A PRACTICAL COURSE IN CONCRETE

BY HENRY GIESE

PORTLAND CEMENT ASSOCIATION

A PRACTICAL COURSE
IN CONCRETE

A Text book for
CLASSROOM AND LABORATORY
Including
DEMONSTRATIONS AND PROBLEMS

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THE activities of the Portland Cement Association, a national organization, are limited to scientific research, the development of new or improved products and methods, technical service, promotion and educational effort (including safety work), and are primarily designed to improve and extend the uses of portland cement and concrete.

The manifold program of the Association and its varied services to cement users are made possible by the financial support of over 70 member companies in the United States and Canada, engaged in the manufacture and sale of a very large proportion of all portland cement used in these two countries. A current list of member companies will be furnished on request.

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The architectural concrete Los Angeles County General Hospital, Los Angeles, Calif., built in 1930. Enough concrete was used in this structure to build forty-two miles of eighteen-foot concrete road.

CHAPTER 1

FOREWORD

Purpose

Concrete as a construction material is eminently suited for many uses. It is durable, sanitary and fire resistant. The upkeep cost of concrete is low, and it can easily be made attractive in appearance. Because it is plastic when first mixed, concrete lends itself well to the construction of many objects.

On the other hand, perhaps no other material depends so much for its success upon the user. Good materials, accurate proportioning and careful control in all operations are essential to the making of good concrete.

This fact makes desirable the organization of practical courses in concrete in our schools.

Many splendid publications relating to concrete are now available. A complete treatise on the subject would require much more space than is available here. However, it is intended that this manuscript provide a teaching background that can readily be supplemented with more detailed material from other sources.

Mere statement of fact often fails to carry its point, whereas demonstrations or practical applications are effective. A number of demonstrations, resulting from presentation to classes of prospective teachers, have been included to illustrate and emphasize points which are important but frequently not observed in actual practice.

Practical concrete work should be allowed enough time to be presented adequately. It should be carried on with a purpose and should lead to an understanding of the properties of concrete, selection of materials, their proper manipulation, and carrying out some actual projects. The exact balance between demonstrations and field practice will depend largely upon the situation at hand and the amount of time available.

Concrete serves in many ways to make travel safe and easy. This bridge spans the Rogue River in Oregon.

Course Objectives

In preparing his course outline the teacher should consider carefully what he expects to accomplish. The following objectives are suggested:

1. To develop an appreciation of the utility and possibilities of concrete and masonry construction.
2. To secure an understanding of the properties of cement and concrete and the importance of good materials and proper manipulation in obtaining a satisfactory product.
3. To develop skill in handling cement and concrete.

A course in concrete offers the teacher the advantages of varied means of presentation for accomplishing the solution of related problems. In general they are:

1. Class recitations and demonstrations.
2. Assigned outside reading and home projects.
3. Laboratory exercises.
4. Field experience and observation.
5. Written work.

Too much emphasis can scarcely be placed upon planning a systematic procedure. After he has the subject matter well in hand, the teacher should plan an attack that will transmit his ideas to his students in the most effective way. He should require complete and well-arranged notes. Since it is difficult to forecast the time and equipment available for the public school course, he should design a flexible course. This involves not only careful arrangement but also the rating of problems so that the most important can be covered in a short course and others can be added if time permits.

Texts and Equipment

Copies of reference books should be in the school library. Many supplementary publications may be obtained from sources given on page 60 of this manual.

Each student should have the following equipment:

1. A good loose leaf notebook (8½x11).
2. Work clothes.
3. About one gallon of bank-run gravel (preferably from the source used at home) to be used in the various tests of aggregates.

Reports

Accurate and carefully prepared reports should be required of all demonstrations and tests covered in the course. These should be arranged and divided so that the organization is apparent.

The following headings have proved satisfactory:

1. Purpose.
2. Equipment used.
3. Method.
4. Results.
5. Conclusions.
6. References.

A fireproof apartment house built of reinforced concrete. All decoration on the outside walls was cast in place as the walls were built.

Interior of the Shrine of the Sacred Heart, Washington, D.C. Rich color effects were achieved in concrete by using exposed colored aggregates.

Flood waters of the Tennessee River, held back by Wilson Dam, Muscle Shoals, Ala., generate electric power for a vast area in southeastern United States. Nearly a mile from end to end, this dam is one of the longest in the world.

If this plan is followed, the report will show essential facts at a glance.

The following demonstrations are suggested. Detailed descriptions are given on the pages indicated.

A—Selection of Materials.

1. Fineness of cement (page 13).
2. Color test for organic materials (page 14).
3. Silt test of aggregates (page 14).
4. Percentage of coarse and fine aggregate in bank run material (page 15).
5. Gradation of fine aggregate (page 15).

B—Theory of Proportioning.

6. Water-cement ratio: demonstration of principle (page 17).
7. Water-cement ratio: beam tests (page 17).
8. Measuring moisture in sand (page 20).
9. Voids in sand and gravel (page 22).
10. Surface area of aggregate (page 23).
11. Bulking of sand (page 26).

C—Reinforcing.

12. Reinforced concrete beams (page 57).

Laboratory Instructions

These general instructions should be followed carefully throughout the laboratory course:

Any equipment needed for demonstration or tests should be returned to its proper place so someone else may use it. The usefulness of testing sieves, scales, etc., depends upon their accuracy. They damage easily, so they must be used with care.

All apparatus must be returned clean and in good condition. To facilitate cleaning of metal forms a thin application of oil is applied with a brush before the concrete is placed in them. When making small test pieces, an oily cloth is preferable for oiling the inside of the molds and the surface of the glass.

After forms are removed they must be cleaned and re-oiled before being put away. This is necessary to protect them for future use.

To avoid confusion, all test pieces must be carefully numbered, dated and preferably marked with the owner's initials.

All reports should be prepared carefully. At the end of each period a fairly complete report should be made of the work done, but certain things must be recorded as the work is carried on. Weights or measurements of materials should be recorded immediately.

Procedure in the Course

In any course, there are problems in choosing the order of presentation. Individual cases may justify the rearrangement of a well-planned course. Seasons and variable weather make it necessary in a course in concrete to take advantage of good days for field work. In general, the order of presentation as given in this manuscript is suggested.

Laboratory work should be correlated very closely with class work. A discussion of the quality of aggregates and the necessity for making certain simple tests should be followed up by making the tests in the laboratory. Likewise, the theory of proportioning might well be accompanied by making test beams and proportioning of concrete in the field. Everything of a theoretical nature should find application in a project of interest to the student.

CHAPTER 2

MATERIALS

Portland Cement

Since, in concrete construction, it is common to buy the materials or ingredients rather than the finished product and since some of these may vary greatly in quality, a course in concrete should begin with a discussion of what concrete is and what materials are needed to make good concrete.

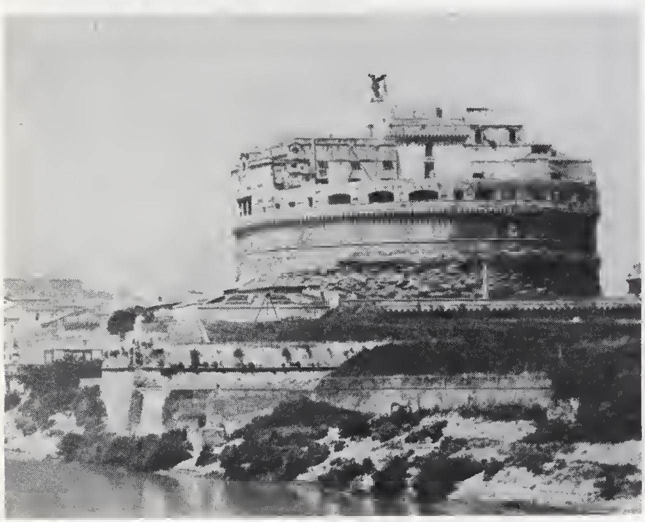
Concrete is a mixture in which a paste of portland cement and water binds fine and coarse materials, known as aggregates, into a rocklike mass as the paste hardens through the chemical action of the cement and water. It is composed, then, of an active material (cement) and inert materials (aggregates). It might also be termed a mass of inert materials held in place by a binder. The binder constitutes the more expensive ingredient. The inert materials are relatively inexpensive. A good concrete has all surfaces of the aggregate thoroughly coated with the paste and all voids filled.

The quality of concrete depends upon the quality of materials, proportioning and workmanship. The economy depends upon the manner in which these are combined to secure a dense, compact mass with a minimum of binder.

Mortar is a mixture similar to concrete in which no large size aggregate is used.

The great dome of the Pantheon in Rome was built of concrete 1,800 years ago.

The Castle of St. Angelo in Rome, built in 138 A.D. as a tomb for Emperor Hadrian. Its massive foundation and walls were constructed of pozzolana concrete, made with natural cement.



History of Cementing Materials

Cements and limes have been used since the dawn of civilization. The famous Appian Way, the great system of aqueducts, and other concrete structures built by the Romans are today in an excellent state of preservation.

Despite the early use of these materials, little was known of their chemistry, and no substantial advance was made in the manufacture of lime and cement from the time of the Romans until 1756. In that year, John Smeaton, who had been employed by the English government to build a lighthouse in the English Channel, discovered that an impure or clayey limestone, when burned and slaked, would harden into a solid mass under water as well as in air. This discovery of Smeaton's led the way to rapid improvement and de-

Horace Greeley residence, Choppoquo, N.Y., built in 1857. This is the oldest concrete house in America.

velopment in the lime and cement industries.

In 1796 James Parker of Northfleet, England, obtained a patent for the manufacture of a cement which he aptly named Roman cement. Parker's process consisted of burning certain stone or clayey products called "nodules of clay" in an ordinary lime kiln, and then grinding the clinkers to a powder. Cement made in this way rapidly gained favor among engineers and builders, and natural cement plants sprang up all over the continent of Europe, in England, and later, about 1818, in the United States.

In 1824 Joseph Aspdin took out a patent in England for the manufacture of an improved cement, produced by calcining a mixture of limestone and clay. To the resulting powder he gave the name of *portland cement*, because, when it hardened, it produced a yellowish-gray mass resembling in appearance the stone found in various quarries on the isle of Portland, England. Joseph Aspdin is given credit for making the first portland cement, and he is generally recognized as the father of the modern portland cement industry.

Aspdin appears to have been the first to realize that superior hydraulic properties were obtainable by harder burning, that is, to proper fusion, instead of solely by calcination as was long the practice. However, he followed the previous practice of pulverizing by slaking and removing by hand larger pieces of unslaked harder-burned material. His cement was not uniformly sound because there still remained some small pieces of the harder-burned clinker. It remained for Isaac Johnson to discover about 1845 that the harder particles after weathering and suitable mechanical grinding yielded a cement of superior qualities. Johnson therefore is more nearly the discoverer of the portland cement we know.

In this country the cement industry began with the discovery in 1818 of a natural cement rock near Chitenango, N.Y., by Canvass White, an engineer on the Erie Canal. In 1825, cement rock was found in Ulster County, N.Y., and in 1828 a mill was built in Rosendale, N.Y.

In the spring of 1866, D. O. Saylor, Esaias Rehrig and Adam Woolever, all of Allentown, Pa., formed the Coplay Cement Co. and located a mill near Allentown for the manufacture of natural cement. Mr. Saylor began early in the seventies to experiment on portland cement from the rock in the quarries. After many experiments and trials, true portland cement was produced in 1875. This was the first portland cement made in the Lehigh district and probably in the United States.

This, then, was the small beginning of the American portland cement industry, which has grown from a production of about 83,000 bbl. in 1880, and less than 1,000,000 in 1895, to the total of 249,000,000 in 1952. (One barrel equals four sacks.)

Modern portland cement is a finely pulverized material consisting principally of certain definite compounds of lime with silica, alumina and iron oxide, which is capable of hardening into a solid mass through chemical combinations of the various compounds with water.

The Manufacture of Portland Cement

An abundance of calcareous and argillaceous materials suitable for the manufacture of portland cement is available. The calcareous variety is generally in the form of calcium carbonate such as limestone, chalk, marl, oyster shells or the precipitated form obtained as a waste product from the manufacture of alkalis. Cement rock combines both calcareous and argillaceous materials in about the correct proportions for portland cement. The argillaceous division also includes clay, shale and slate. Selected blast furnace slag, iron ore and sand are frequently used. Cement is made in this country from all these materials, each plant using one or

Quarrying limestone, one of the principal ingredients of portland cement.

more of the calcareous materials in combination with one or more of the argillaceous materials.

Portland cement may also be divided into classes according to the method of manufacture:

1. Wet process.
2. Dry process.

In the wet process, the raw materials, properly proportioned, are intimately mixed, ground and fed in the form of a "slurry" (containing enough water for a fluid consistency) into the rotary kilns. In the dry process, raw materials are ground, mixed and fed to the kiln in a dry state.

The various operations in the manufacture of portland cement by the dry process are:

1. Mining and quarrying of raw materials.
2. Crushing.
3. Drying.
4. Grinding.
5. Proportioning and mixing.
6. Pulverizing.
7. Burning the mixed materials to incipient fusion.
8. Grinding the clinker thus burned to an extremely fine powder, meanwhile adding the proper proportion of gypsum; the resulting powder is known as portland cement.

In the wet process, instead of drying raw materials, water is added, and the further operations of grinding, proportioning, mixing, etc., to insure absence of lumps or foreign material are carried out on the slurry, which is usually pumped or fed by gravity from stage to stage in the process. In some plants, part of this water is removed by filtration before burning. Some plants combine grinding and pulverizing into a single operation. Otherwise, the wet and dry processes are essentially alike.

In both the wet and dry process, tanks or bins are provided for blending the raw materials after final grinding so that the composition can be closely adjusted to meet the exacting requirements of modern specifications.

Excavation of raw materials is the first step toward the actual manufacture of portland cement. The natural raw materials are worked by one of three general methods: (1) quarrying and digging from open pits; (2) mining from underground workings; (3) dredging from deposits covered by water.

The method of quarrying the rocks usually follows custom. The rock is dislodged from the quarry face by an explosive and loaded into cars or trucks, usually by power shovel. The stone is next conveyed to the stone house where it is crushed to comparatively small sizes, dried, and then transported to storage bins before being mixed with the other ingredients. While in storage, the stone may be sampled and analyzed. Another method is to pass the limestone, shale or cement rock through crushers and ball mills, or other preliminary grinders, from which it is conveyed to storage bins. Ball mills are revolving cylindrical steel drums containing a quantity of steel balls. The dried material to be ground is continuously added. As the cylinder rotates, the balls roll, grinding the rocks to coarse grits. The coarse grits are then run into storage bins.

Shale, which for practical purposes may be looked upon as solidified clay, is excavated, dried, ground and then conveyed to storage bins.

After the raw materials have been drawn from their respective bins and accurately proportioned by weighing, they are delivered to a screw conveyor which delivers the combined material to the tube mills. The tube mills are similar to ball mills but of greater length. These reduce the material to practically the fineness of finished cement.

The proportioned and ground raw material is then delivered by a system of conveyors or pumps to blending bins from which it is drawn to provide feed of the desired composition for the kiln. At frequent intervals, samples are taken from the conveyors or pumps and delivered to the laboratory for composition tests.

The kilns themselves are revolving cylinders from 6 to 12 ft. in diameter and from 100 to 500 ft. long. They are lined with refractory brick and revolve at the rate of about one revolution per minute. Powdered bituminous coal, crude oil or gas is used as fuel. It is blown into the kiln at the end opposite that at which the raw materials enter.

It is estimated that a particle of raw material takes one to several hours to transverse the entire distance from the feed to the outlet. The raw material entering as a powder (in the wet process as slurry or cake) is gradually brought to the point of incipient fusion at a temperature of 2,500 deg. to 3,000 deg. F., producing clinkers varying in size up to about 1½ in. in diameter. Through dark glasses, experienced workmen observe the condition within the kiln and regulate the speed or fuel supply to obtain the desired burning conditions. The clinker, red-hot when discharged, is soon cooled by cold-air blasts in rotary or specially designed coolers. Sometimes water is sprayed on the clinker as it comes from the kiln.

A portland cement mill. More than 160 such plants in every part of the United States, supply the cement needed for modern construction.

From the kiln, the clinker may go (a) to the clinker storage pile for later grinding, or (b) directly to the grinding department.

Either before or after the preliminary grinding of the clinker, it is usual to add approximately 4 lb. of gypsum to every 100 lb. of clinker to regulate the setting time of the cement. This is controlled by the chemist from analyses of the finished cement and from "the time of setting" determinations made hourly in the physical laboratory.

After the gypsum has been added, the material is delivered to the tube mills, which complete the grinding. The fineness to which the cement is ground is controlled by measurements of the surface area or by the percentages passing a given sieve. In the average cement of today 94 to 97 per cent or more will pass a sieve having 40,000 openings per square inch. Tests for surface fineness are made on the hourly samples mentioned above.

The cement is deposited in storage bins, similar to those used in storing grain, by means of conveyors or pumps. Before packing or loading, the cement is passed through a coarse screen. Much cement now used is shipped in bulk direct to the construction operation. Cement not shipped in bulk is sold in paper or cloth sacks. For package shipment the cement is transported to large hoppers above the packing machines. A cement sack is first tied and then filled by machine through a valve or flap in the bottom. The valve may be discovered by carefully inspecting any standard sack used today. The filled sacks are placed on a conveyor belt which unloads them within a few feet of the car, ready for shipment.

Setting and Hardening of Portland Cement

When portland cement is mixed with enough water to form a paste, the compounds of the cement react with the water to form both crystalline and jellylike products. These products adhere to the aggregate and to each other and become very hard. If the concrete is kept moist, the reactions may continue for years, and thus the product becomes progressively stronger over a long period of time.

In huge revolving kilns, cement is burned at temperatures exceeding 2,700 deg. F. Rotary clinker cooler is shown under kiln.

The impression of an ash leaf on a concrete pavement, photographed after 18 years of exposure to traffic and weather—remarkable evidence of the durability of concrete.

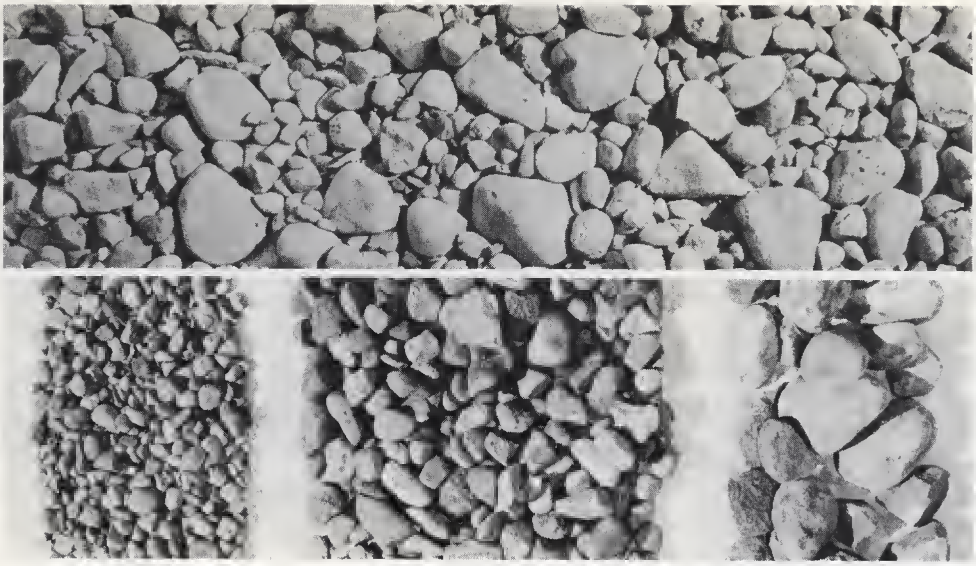
When water is first added to the cement, the paste thus produced remains plastic for a short time but as the reactions with the water proceed, the mix begins to stiffen or "set". At the early stage of the "setting", it is still possible to disturb the material and remix without injury, but as the reactions between the cement and water continue, the mass completely loses its plasticity, and if disturbed or remixed, its strength will be seriously impaired. This early period in the hardening of cement is spoken of as the "setting period", although there is no well-defined break in the hardening process. Once the mass has definitely hardened, the chemical action continues, building up a firm internal structure which increases in hardness and strength as the action proceeds. The set and subsequent hardening process are the same whether the cement is used alone or in combination with aggregates.

Special Portland Cements

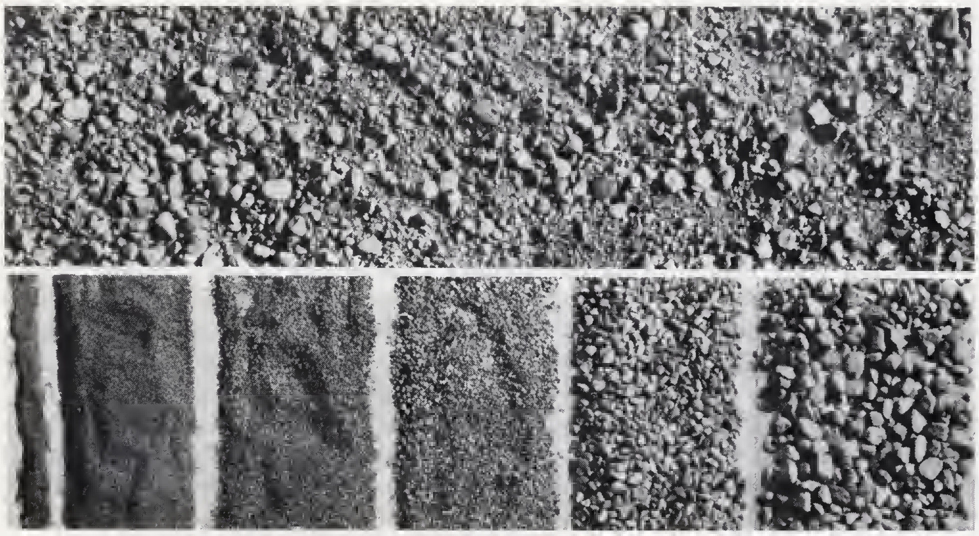
Special portland cements have been developed for specific uses. Portland cement as ordinarily marketed is grayish in color and is often termed *gray* portland cement. Where whiteness is an added advantage for making white or colored concrete one can obtain *white* portland cements made from carefully selected raw materials. These white cements conform in all respects to the chemical limitations and strength requirements of specifications for normal portland cement.

Other cements are now available for special purposes. Examples of these are the *high-early-strength portland cements* which harden more quickly than normal portland cements and fill the need where high-early-strength concrete is desired.

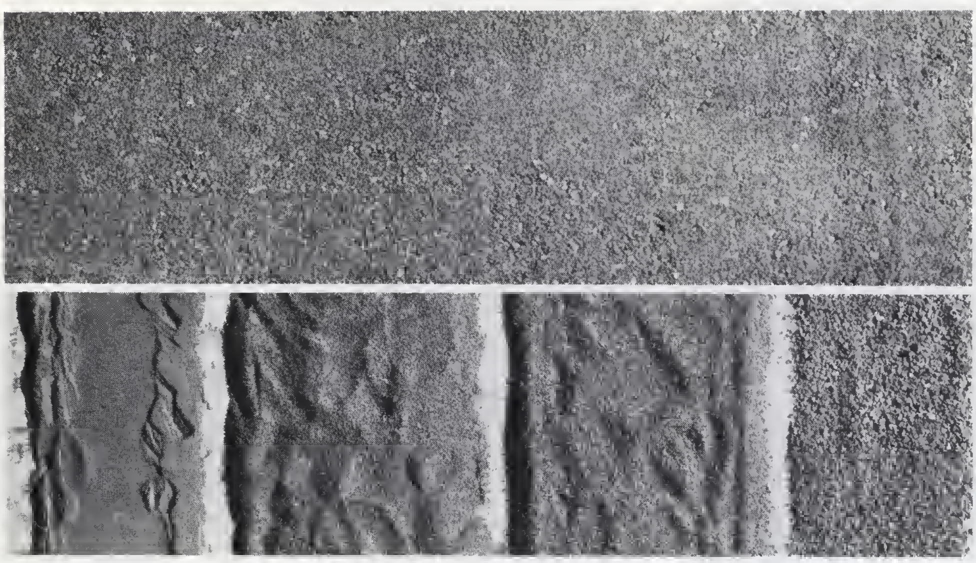
Another special type of cement which has come into use in recent years is low-heat cement, first developed



This is how a well-graded coarse aggregate looks before and after being separated into three sizes. From left to right in the separated aggregate: ¼ to ⅜ in., ⅜ to ¾ in., ¾ to 1½ in. Note how smaller pieces fit in among larger ones in the mixed aggregate.



Sample of well-graded sand before and after separating into various sizes. Particles vary from fine to those just passing the No. 4 sieve. Width of strip indicates amount of each size.



Sample of sand which lacks particles larger than 1/16 in. More cement is required when sand is fine. This is not a good concrete sand.

for use in the Hoover Dam. In huge masses of concrete the heat generated in hardening, with the cements previously available, would have created problems of heat dissipation very difficult to handle. Heat is generated by the chemical reactions incident to hardening with all hydraulic cements and the rate at which it is developed is greater the more rapid the hardening. Fortunately high strengths at the early period are not needed for massive structures, so that the changes in composition necessary to give a much slower evolution of heat do not introduce any problems of strength.

Following the development of low-heat cement for extremely large dams the next step was the introduction of a cement intermediate in heat evolution which would be suitable for structures intermediate in mass. Thus there are now four types of cement varying in heat and strength characteristics from high-early-strength rapid-hardening cements through intermediate stages to the slow-hardening low-heat cement.

Another special cement is sometimes used to give greater resistance to the corrosive action of ground water in sulfate soils. This is referred to as sulfate-resisting cement.

Very recently air-entraining cement has been added to the list of special cements. This product, obtained by grinding a small quantity of some so-called "air-entraining agent" with the cement, has the property of introducing millions of air bubbles of microscopic size into a few cubic inches of concrete. The effect of this entrained air, when kept within proper limits, is to increase greatly the resistance of the concrete to damage by frost action. The air-entraining agents and the amount in which they can be used in cement are controlled by applicable specifications.

Cement clinker, before grinding, is not easily affected by water. The finished cement held in storage may be damaged by water and may even absorb moisture from the atmosphere in time unless properly protected. Therefore cement should be kept in a dry place at all times before use. Cement containing lumps that cannot be pulverized by striking lightly with a shovel should not be used. Cement that is caked because of the weight of cement piled on it can be reconditioned by rolling the sack on the floor.

Fineness of Cement (*Demonstration No. 1*). The fineness to which cement is ground and the way fineness of grinding affects early hardening may be demonstrated easily.

Screen the cement in turn through the 100-mesh and 200-mesh sieves, saving the material retained on each. Note how little cement is retained and how much original material must be screened to secure a sample large enough to make a small pat.

Make a paste of water and (1) cement retained on the 100-mesh sieve, (2) cement passing the 100- but retained on the 200-mesh sieve, (3) cement passing the 200-mesh sieve. Place in small molds so that each may be observed later under identical conditions. After 48 hours, note the difference in character of the three specimens. The coarser particles are almost entirely lacking in cementing power.

Mixing Water

In general, water that is fit to drink is suitable for mixing with cement. Water should be clean and free from oil, alkali or acid.

Aggregates

The selection of aggregates is of particular importance in the making of concrete. Both the cost and the quality of the concrete are affected by the kind of aggregates selected. A good rule is to use aggregates from sources known to make good concrete, or to obtain them from reliable dealers. If it is necessary to use aggregates of unknown quality, they should be carefully examined and tested to make sure they are suitable for making concrete. Requirements of good aggregates and methods of making tests to determine whether they contain harmful amounts of silt and organic matter are given in the following paragraphs.

Bank-Run Gravel

Sand and gravel suitable for concrete often are found as bank-run gravel. This means the natural mixture of sand, gravel and stone as it comes from a gravel bank.

Bank-run gravel, however, is rarely found in the proper mixture of sizes to make the best quality concrete; therefore it is usually necessary to screen it into two sizes. Gravel not larger than 1½ in. in diameter is suitable for most construction. Occasionally, for thick foundations and other heavy sections, larger stone can be used to advantage. However, the larger stones are likely to prove troublesome in thin sections like water tank walls and thin foundations. Where big stones occur in large number in bank-run gravel, it is advisable to screen the material first over a 1½-in. screen. Material failing to pass this screen is discarded. Material passing through the 1½-in. screen should then be shoveled over a No. 4 screen (4 openings to the inch). That part passing through the ¼-in. screen is the sand or fine aggregate, and the material remaining is gravel or coarse aggregate.

Frequently this aggregate is not clean enough for use until it is washed to remove silt, clay or other materials detrimental to good concrete mixtures. Since clean aggregates are so essential to quality concrete, washing is well worth the effort.

Sand particles for concrete should be clean and hard and range in size from very fine up to those which will just pass a No. 4 screen (4 openings per lineal

The color test is used to detect the presence of harmful amounts of organic matter in aggregates. A colorless liquid indicates aggregate free from organic matter. A slightly colored liquid indicates presence of some organic matter but not enough to prove injurious. A dark liquid, as in the right hand bottle, shows that the aggregate is unsatisfactory for concrete work unless the organic matter is washed out.

inch). Fine stone screenings are sometimes used as sand.

Gravel should be clean and hard and made of pebbles varying in diameter from ¼ in. to 1½ in. for most work. Crushed stone or crushed slag may be used as gravel. The largest pieces of gravel or crushed stone should never be greater than one-third the thickness of the wall or floor being built.

In addition to being sound, hard and durable, the best aggregates are clean and free from loam or vegetable matter. These materials are objectionable because they prevent the cement paste from binding together the particles of sound, durable aggregates, thereby reducing the strength of the concrete and making it more porous. Concrete made with dirty aggregates hardens slowly and may never harden enough to serve its intended purpose.

Methods for making tests to determine whether aggregates contain harmful amounts of vegetable matter or silt are outlined below.

Color Test (*Demonstration No. 2*). The color test is a reliable indicator of the presence of harmful vegetable matter except in areas where there are deposits of lignite. It is particularly valuable when locating a new sand supply.

Fill an ordinary 12-oz. prescription bottle, such as druggists use, to the 4½-oz. mark with a sample of the sand. To this add a 3 per cent solution of caustic soda (sodium hydroxide) until the 7-oz. mark is reached. A 3 per cent solution of caustic soda is made by dissolving 1 oz. of sodium hydroxide, which can be purchased at any drug store, in a quart of water, preferably distilled. The solution should be kept in a glass bottle tightly closed with a rubber stopper. Handling sodium hydroxide with moist hands may result in serious burns. Care should be taken not to spill the solution, for it is highly injurious to clothing, leather and most other materials.

As soon as the solution of sodium hydroxide is added to the sand, the contents of the bottle are thoroughly shaken and then allowed to stand for 24 hours. At the end of this time the color of the liquid will indicate whether the sand contains dangerous amounts of vegetable matter. A colorless liquid indicates a clean sand free from vegetable matter. A straw-colored solution indicates some vegetable matter but not enough to be seriously objectionable. Darker colors mean that the sand contains injurious amounts and should not be used unless it is washed, and a retest shows that it is then satisfactory.

Silt Test (*Demonstration No. 3*). The silt test is used to detect the presence of too much extremely fine material.

Fill an ordinary quart milk bottle or quart fruit jar to a depth of 2 in. with a representative sample of dry sand. Add water until the bottle or jar is about three-fourths full and shake vigorously for one minute, the last few shakes being in a sidewise direction to level off the sand. Allow the jar to stand for an hour, during which time any silt present will be deposited in a layer above the sand. If this layer is more than ⅛ in. thick, the sand from which the sample is taken should be washed to remove the excess silt.

A quart fruit jar may be used to make the silt test for sands.

Gradation of Aggregates

Most gravel banks contain more sand than is desirable for best results. Moreover, the mixture is not uniform throughout the bank. A well-graded mixture, uniform from batch to batch, is highly desirable.

The following tests are designed to show the probable suitability of the material and also to show whether more coarse aggregate should be obtained.

Percentage of Coarse and Fine Aggregate in Bank Run (*Demonstration No. 4*). Screen a measured quantity of bank-run material, preferably 3,000 grams or more, through a No. 4 sieve. Weigh material retained on the sieve and that passing through it, as a check. Calculate percentages. For most work there should be at least as much coarse as fine aggregate, and for some work one can profitably use nearly twice as much coarse.

Gradation of Fine Aggregate (*Demonstration No. 5*). The gradation of fine aggregate can be checked with the laboratory sieves. It should be well graded and fall within the limits given below:

Sieve	Percentage Passing
3/8-in.	100
No. 4	95 to 100
No. 16	45 to 80
No. 50	10 to 30
No. 100	2 to 10

Take 1,000 grams of fine aggregate and screen through each of the above sieves in turn. Weigh each time the amount passing through the sieve and that retained upon it. Why? Calculate percentages.

Well-graded fine aggregate is recommended in which the particles are not all fine or all coarse but vary from fine up to those particles which will just pass a screen having meshes 1/4 in. square. If the sand is well graded, the finer particles help to fill the spaces (voids) between the larger particles, thus resulting in the most economical use of cement paste in filling the voids and binding the aggregate together to form strong concrete.

Coarse aggregate is well graded when the particles range from 1/4 in. up to the largest size which may be used on the kind of work to be done without a considerable excess of any one size.

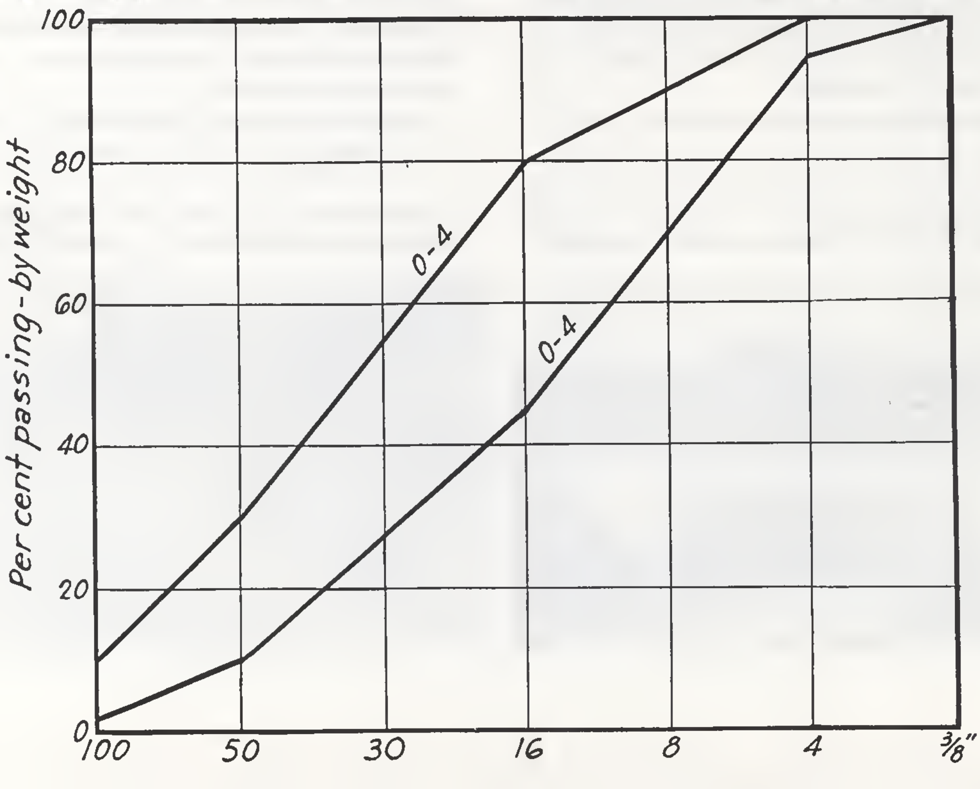
Photographs on page 12 show how well-graded aggregates look before and after being separated into the various sizes. Note that the smaller particles fit in among the larger ones.

In addition to natural aggregates, cinders and specially prepared materials are sometimes used. For further discussion of these, see Chapters 6 and 7.

Questions

1. What is portland cement?
2. What are the raw materials used in the manufacture of portland cement?
3. How is portland cement made?
4. What is meant by "setting of cement"?
5. What is concrete?
6. What is mortar?
7. What are aggregates?
8. Why should aggregates be well graded?
9. What is bank-run gravel?
10. What are the requirements of a good concrete aggregate? What simple tests should be applied with equipment available in a school laboratory?
11. What is a safe rule to follow in the selection of water for use in concrete?

Standard sizes of square mesh sieves. Curves indicate sand limits in "Standard Specifications for Concrete Aggregates", ASTM Designation C33-46



CHAPTER 3

PROPORTIONING

Essential Properties of Concrete

The two principal requirements of hardened concrete are strength and durability—strength to perform the functions of the structure and durability to resist exposure to the elements—and they should be the governing considerations in the design of mixtures. A third element, economy, is not so important on small jobs as either durability or strength, but it becomes increasingly important as the amount of concrete to be placed increases. A fourth requirement is workability during placing. A successful design will achieve a proper balance among these four essentials; the mixture will be placeable in the proper degree; it will represent an economical use of the available materials; and when hardened it will provide necessary strength and resistance to weathering agencies. In the pages which follow, the detailed procedure for arriving at such a design is presented.

Predetermining Quality

Quality of the Cement Paste

As previously stated, concrete is a mass of fine and coarse materials, known as aggregates, which are surrounded and held together by hardened portland cement paste. If the paste is strong and the aggregates hard, the concrete is strong. If the paste is watertight, the concrete is watertight. If the paste and aggregates are durable, the concrete is durable.

When the materials for concrete are first mixed together, the cement and water form a paste which surrounds the particles of aggregate and holds them together in a plastic mass. A chemical action between the cement and water causes the paste to harden.

If too much water is added, the paste becomes thin or diluted and will be weak when it hardens. A paste of this kind will not hold the particles of aggregate firmly together. On the other hand, cement paste which has good binding qualities will hold the particles of aggregate firmly together to make strong concrete. *The potential quality of this paste is determined by the quantity of water mixed with the cement.*

Concrete that will be strong, durable and watertight can be produced through the use of suitable materials, correct proportioning, and careful mixing, placing, finishing and curing. The direct relation between strength of concrete and the relative quantities of water and cement in the mixture is expressed by the water-cement ratio strength law:

> *For given materials and conditions of handling, the strength of concrete is determined primarily by the ratio of the volume of mixing water to the volume of cement as long as the mixture is plastic and workable.*

In other words, if 6 gal. of water is used for each sack of cement in a mixture, the strength at a certain age is practically fixed, regardless of what quantities of aggregate are used, *as long as the mixture is plastic and workable* and the aggregates are clean and made up of sound particles.

In the laboratory studies leading to the discovery of this principle it was found that, unless the mixtures

Reinforced concrete rigid frame bridges are used extensively in eliminating dangerous intersections of highways or highways and railroads.

Concrete highways carry traffic in every state of the Union. A highway such as this, divided by a parkway, adds to driving safety.

Concrete is widely used for attractive, modern industrial buildings.

were of such consistency that they could be readily molded into a dense, compact mass, the strength results did not conform to the general relationship. Likewise, in the studies of watertightness it was found that, unless the mixtures were easily placcable and at the same time not so fluid as to segregate in placing, no regular relationship existed between watertightness and quantity of mixing water. Segregation means a separation of the coarse from the fine materials. The need for this plastic consistency during construction is just as important as in the laboratory studies if the concrete in the structure is to have the properties for which it is being designed. True plasticity means a mixture neither too wet nor too dry. Overwet mixes segregate in handling; too dry mixes cannot be compacted properly.

The hardening of the cement-water paste results from the chemical reactions between the water and cement. For completion, these reactions need time, moisture, and favorable temperatures. During this process of hydration a certain amount of water combines chemically with the cement to become a part of the permanent solid structure of the concrete. To obtain plastic mixtures more water is used than can be permanently combined with the cement even with the most extended curing. A certain amount of water, therefore, remains uncombined and distributed within the paste. The space it occupies will be represented by air voids as the water evaporates. Thus both the quantity of water used and the extent of the curing directly affect the watertightness of the paste, and through it the watertightness and durability of the concrete.

In view of the dependence of the properties of the concrete upon the quality of the paste, it will be seen that as far as proportioning is concerned the relative amounts of aggregate and cement are important only insofar as they affect the workability and the cost; provided, of course, that the mixes are truly plastic and workable.

Designing a concrete mix, therefore, consists of selecting the water-cement ratio which will produce concrete of the desired resistance to exposure and the required strength, and finding the most suitable combination of aggregates which will give proper workability when mixed with cement and water in this ratio.

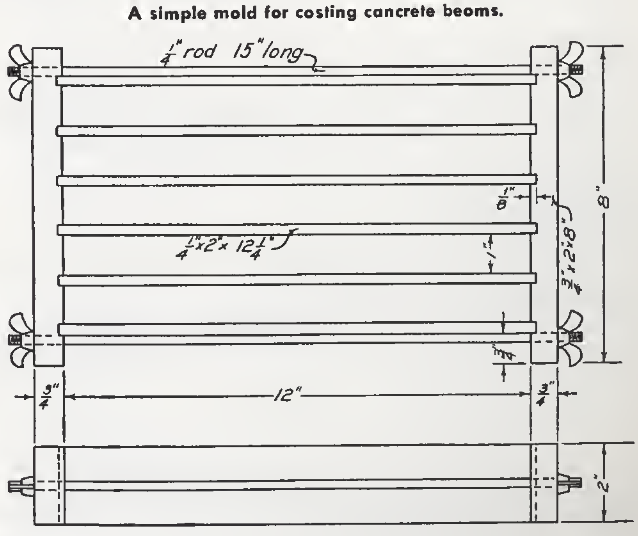
Water-Cement Ratio: Demonstration of Principle (Demonstration No. 6). Although this principle has been in practical use a number of years, its significance is still not fully appreciated. Its importance in securing concrete of a predetermined quality justifies some classroom time in demonstrating its effect.

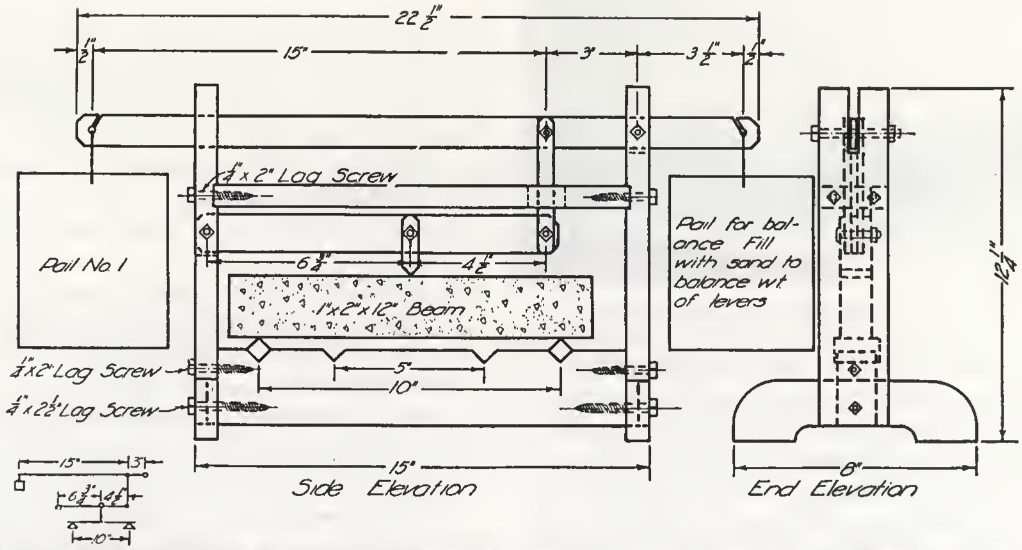
1. Take two strips of paper. Coat one end of each with library paste as it comes from the jar. Press together and note cementing property of the paste.
2. Dilute a small quantity of paste with water and make the same test with diluted paste, noting impaired cementing property.
3. Mix a small quantity of library paste with sand, noting the change in workability as more sand is added; mold into cube when the quantity of sand added seems to have reached the point that any additional would impair the workability. Show that strength of cube will depend upon the strength of the paste.
4. Repeat the above with diluted paste.
5. Mix 40 cc. water and 50 cc. portland cement into a paste and then gradually add sand to show change in workability.
6. Compare function of portland cement with other pastes and cements. Show that the strength of the concrete is dependent upon the ratio of quantity of water to the quantity of cement (gallons per sack).

Water Cement Ratio: Beam Tests (Demonstration No. 7). The law can be demonstrated further by the use of concrete test specimens. Compression tests on cylinders will give the best results. However, equipment for testing these is usually not available in a school shop nor easily made. Beams can be used to accomplish approximately the same result. They are easily made and can be tested by equipment made in the school shop.

Accompanying drawings show how to make a form for casting beams and a device for testing them. Beams should be at least 1 in. wide by 2 in. deep by 12 in. long.

A simple mold for casting concrete beams.





A device for testing concrete beams which can be made at home or in a school manual training department. Oak lumber is best for this purpose. To find magnitude of concentrated load in center of beam causing failure, multiply weight of pail No. 1 by 10.

Make at least four beams each with water-cement ratio varying as follows: 5, 6, 7, 8 gal. to the sack of cement. Calculate quantities carefully. Be sure to fill molds completely. Allow concrete to stand about an hour before smoothing off the top. After 24 hours, remove beams from the mold, mark them with a suitable identification and place in water for 28 days.

When dry, test each beam in the machine. Average the results of all beams made from each mix. Averages should be compared rather than individual results as considerable variation may occur. Compare breaking loads.

TABLE 1—SUGGESTED PROPORTIONS OF WATER TO CEMENT FOR VARIOUS KINDS OF CONCRETE WORK AND TRIAL MIXES

KINDS OF WORK	Add U.S. gal. of water to each sack batch if sand is:			Trial mixture			Materials per cu.yd. of Concrete*		
					Aggregates			Aggregates	
	Very wet	Wet	Damp	Cement sacks	Fine, cu.ft.	Coarse, cu.ft.	Cement sacks	Fine, cu.ft.	Coarse, cu.ft.
5-GAL. PASTE FOR CONCRETE SUBJECTED TO SEVERE WEAR, WEATHER OR WEAK ACID AND ALKALI SOLUTIONS									
Toppings for two-course work. One-course industrial, creamery and dairy plant floors.	3¾	4	4½	1	1¾	3 Maximum size 1½ in.	7	12½	21
Thin sections of dense, strong concrete.	3½	4	4½	1	2	2¼ Maximum size ¾ in.	7¾	15½	17½
6-GAL. PASTE FOR CONCRETE TO BE WATERTIGHT OR SUBJECTED TO MODERATE WEAR AND WEATHER									
Watertight floors such as industrial plant, dairy barn, basement, etc. Watertight basement walls. All watertight concrete for storage tanks, septic tanks, swimming pools, etc.	4¼	5	5½	1	2½	3½ Maximum size 1½ in.	6	15	21
Concrete subjected to moderate wear or frost action such as walks, driveways, tennis courts, etc. Reinforced structural beams, columns, slabs, etc.	4	4¾	5½	1	2¾	2¾ Maximum size ¾ in.	6½	18	18
7-GAL. PASTE FOR CONCRETE NOT SUBJECTED TO WEAR, WEATHER OR WATER									
Foundation walls, footings, mass concrete, etc.	4¾	5½	6¼	1	3	4 Maximum size 1½ in.	5	15	20
	4½	5½	6¼	1	3¼	3 Maximum size ¾ in.	5½	18	16½

*Quantities are estimated on wet aggregates, using trial mixes and medium consistencies (3-in. slump). Quantities will vary according to grading of aggregate and consistency of mix. Change proportions of fine and coarse aggregate slightly if necessary to get a workable mix. Quantities are approximate. No allowance has been made for waste.

NOTE: If concrete aggregates are sold in your locality by weight, you may assume for estimating purposes that a ton contains approximately 22 cu.ft. of sand or crushed stone; or about 20 cu.ft. of gravel. For information on local aggregates consult your building material dealer.

Determining the Quality of Paste for Specific Uses

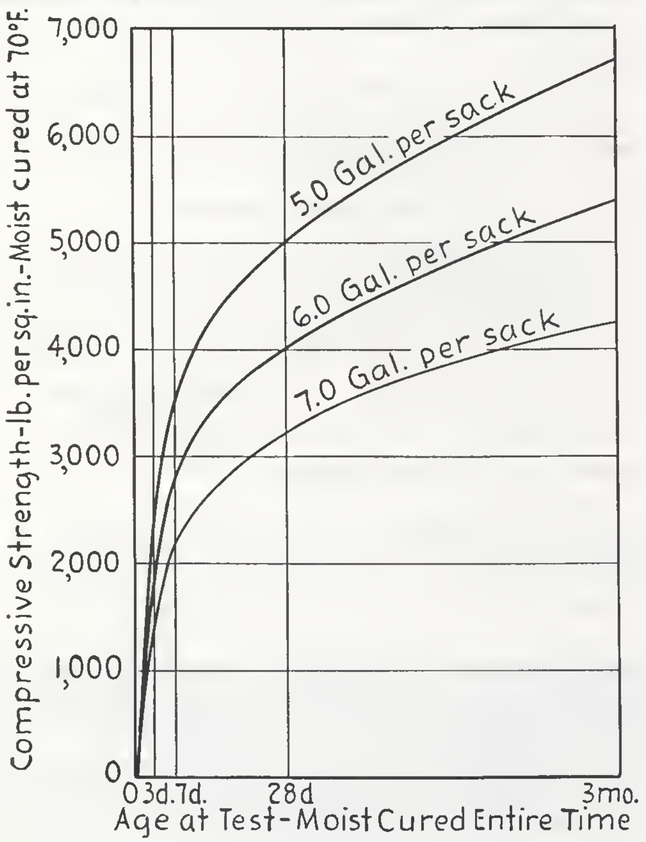
It is an easy matter to proportion concrete by methods which control the total amount of water mixed with each sack of cement and thus control the quality of the concrete.

Some jobs require better quality concrete than others. A concrete water tank, for example, must be watertight and much stronger than an ordinary concrete footing. Because the cement paste in concrete for a water tank must be watertight, less water is used than for a concrete footing which need not be watertight nor so strong.

Recommended qualities of concrete for various classes of work are listed in Table 1, which is the guide to proportioning concrete materials according to the total amount of water required with each sack of cement. This table is based on the following facts:

1. A cement paste made in a proportion of not more than 5 gal. of water to 1 sack of cement will produce satisfactory concrete for work subjected to severe wear, weather, or weak acid and alkali solutions.
2. A 6-gal. paste produces concrete which is watertight and is satisfactory when subjected to moderate wear and weather.
3. A 7-gal. paste will produce concrete which is suitable for use where it will not be subjected to wear, weather or water pressure.

The effect of quantity of mixing water on the strength of concrete is shown in this graph.



Note that not only the water-cement ratio used, but also the maximum size of coarse aggregate influences materially the amount of cement required to make a cubic yard of concrete.

For convenience in measuring quantities where less than a bag of cement will be used Table 2 shows the amount of water, in pints, for mixes of 5 and 6 gal. per sack of cement with very wet, wet and damp sand.

TABLE 2—PINTS OF WATER TO ADD TO MIXER FOR BATCHES USING 1/2, 1/4, 1/5 AND 1/10 SACKS OF CEMENT

SIZE OF BATCH	Pints of mixing water to add			
	Very wet sand	Wet sand	Damp sand	Dry sand
5 GAL. WATER PER SACK OF CEMENT				
1/2 sack	14	16	18	20
1/4 sack	7	8	9	10
1/5 sack (18.8 lb.) . .	5 3/5	6 2/5	7 1/5	8
1/10 sack (9.4 lb.) . .	2 4/5	3 1/5	3 3/5	4
6 GAL. WATER PER SACK OF CEMENT				
1/2 sack	17	20	22	24
1/4 sack	8 1/2	10	11	12
1/5 sack	6 4/5	8	8 4/5	9 3/5
1/10 sack	3 2/5	4	4 2/5	4 4/5

Effect of Moisture in Sand

After selecting the total amount of water to be used with each sack of cement to make a paste of the quality desired, it is necessary to take into account the amount of water carried by the fine aggregate, as this moisture is free to react with the cement in forming the cement paste. The amount carried by coarse aggregate is generally so small that it can be overlooked.

Table 1 shows how much allowance should be made for sand that is *damp*, *wet* or *very wet*, the amounts being based on suggested trial proportions of aggregates of the maximum sizes listed.

Dry sand is material which is as dry as it would be if it were spread out in a thin layer and dried in the sun or warm air. Such sand, which flows freely, is seldom available for concrete work.

Damp sand is that which feels slightly damp to the touch but which leaves very little moisture on the hands. Damp sand usually contains about ¼ gal. of water per cubic foot (about 2 per cent by weight).

Wet sand, which is the kind usually available, feels wet and leaves a little moisture on the hands after being handled. Wet sand contains approximately ½ gal. of water per cubic foot (about 4 per cent by weight).

Very wet sand is dripping wet when delivered on the job and leaves more moisture on the hands than wet sand. Very wet sand carries about ¾ gal. of water per cubic foot. When it contains considerable fine material,

Moisture in sand. *Left*—If sand falls apart it is damp. *Center*—If sand forms a ball it is wet. *Right*—If sand sparkles and wets the hand it is very wet

it may carry as much as $1\frac{1}{4}$ gal. per cubic foot (from 6 to 10 per cent by weight).

Measuring Moisture in Sand (*Demonstration No. 8*). Whether sand is *damp*, *wet* or *very wet* can be determined by the appearance and feel of materials in these conditions.

To become familiar with the appearance and feel of damp, wet or very wet sand, fill a clean cement sack about two-thirds full of sand from the supply that will be used on the job. Spread this material in a thin layer on a clean, dry floor or on heavy paper or on canvas inside a building and let it dry. Stir the sand until all surface moisture disappears and the sand flows freely.

Measure out 3 gal. of this dry sand, placing 1 gal. in each of three pans after dampening the inside surfaces. A 2-qt. jar may be used for measuring, two jars to each pan. Then, using a prescription bottle as a measure, add $4\frac{1}{4}$ oz. of water to one pile, $8\frac{1}{2}$ oz. to another and $12\frac{3}{4}$ oz. to the third, mixing each thoroughly.

The pile containing $4\frac{1}{4}$ oz. of water is typical of *damp* sand; that containing $8\frac{1}{2}$ oz. is considered *wet* sand, and that containing $12\frac{3}{4}$ oz. is *very wet*. The appearance and feel of these piles should be studied and compared until the difference between damp, wet and very wet materials can be determined readily. The average condition of sand on the job is wet.

Whenever sand is obtained from a different source of supply where it may be finer or coarser, the foregoing test should be repeated for each new sand in order to estimate more closely whether the material is damp, wet or very wet.

In building heavy-duty floors, colored concrete and similar work where accurate control is required, it is necessary to know exactly how much water is contained in sand rather than to classify it as damp, wet or very wet. There are several methods of determining accurately the amount of moisture carried by sand. However, the following is considered a fast, accurate and simple method for use on the job:

In this method the moisture is evaporated by burning denatured alcohol. This is done by placing a weighed sample of the sand (usually 2 lb.) in a shallow pan, pouring alcohol (about $\frac{1}{3}$ cupful for each pound) over the sand, stirring the mixture and then spreading it in a thin layer over the bottom of the pan. Ignite the alcohol and allow it to burn until consumed, stirring the sand slowly during burning. If the sand still appears to carry surface moisture, it is advisable to repeat the burning process to insure drying of the sample. After burning, the sand is allowed to cool for a few minutes and is then weighed. The percentage of water is then calculated.

Suppose 2 lb. of sand being tested for moisture content weighed 1.9 lb. after drying. The total percentage of moisture then would be:

$$\frac{2-1.9}{1.9} \times 100 = 5.\ 3 \text{ per cent}$$

This sample, then, contains 5.3 per cent moisture.

Another simple method based on the same principle is to dry a sample of sand in an oven or over an open fire, heating only until surface moisture disappears. When the weight before and after drying is known, the percentage of moisture may be calculated.

A far cry from the little red schoolhouse is this streamlined concrete schoolhouse.

Determining Suitable Proportions

After the sand to be used is classified as damp, wet or very wet, Table 1 may be used to determine the trial proportion for any particular job. Suppose, for example, it is desired to determine the proper proportion of materials, including water, for building a water tank. For this class of work the concrete must be watertight and able to withstand severe exposure.

Table 1 specifies a 6-gal. paste for concrete to be used in a water tank. However, for a trial batch using 1 part cement, $2\frac{1}{2}$ parts fine aggregate and $3\frac{1}{2}$ parts coarse aggregate, customarily designated as 1: $2\frac{1}{2}$: $3\frac{1}{2}$, made

with damp sand, only 5½ gal. are added at the mixer because approximately ½ gal. is contained in the 2½ cu. ft. of sand. With wet sand, which is the kind usually available on the job, only 5 gal. are added. With very wet sand, only 4¼ gal. are added.

In making a trial batch, first wet the mixer drum. Then place in the mixer the correct amount of water, depending on the condition of the aggregates; add 1 sack of cement, 2½ cu.ft. sand, and 3½ cu.ft. of coarse aggregate; and mix all ingredients for at least one minute and preferably for two. By noting how this concrete handles and places, it readily can be determined whether changes in the proportions are necessary in remaining batches.

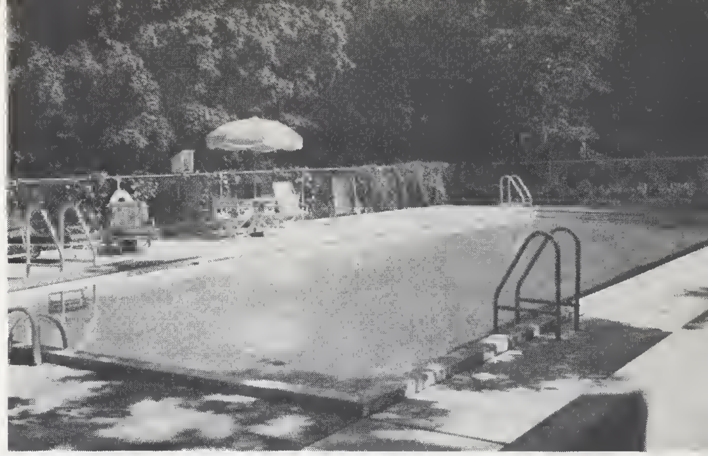
If the concrete in the trial batch is a smooth, plastic, workable mass that will place and finish well, the correct proportions for the job have been determined. The suitability of the proportions can be judged by working the concrete with a shovel or a trowel. The concrete should be stiff enough to stick together yet not dry enough to be crumbly. On the other hand, if the concrete is thin enough to run, it is not suitable for use. The best mixture is mushy but not soupy.

Concrete that places and finishes readily is known as workable concrete. In a workable mixture there is sufficient cement paste to bind the pieces of aggregate together so that they will not separate when the material is transported to or placed in the forms. There is also sufficient cement paste and sand to give good, smooth surfaces free from rough spots, called honeycombing. In other words, there is just enough cement paste to fill completely the spaces between the particles of aggregate and to insure a plastic mix that finishes easily.

A mixture that is workable for one job, however, may be too stiff for another; that is, concrete to be placed in thin sections must be more plastic than if used in heavier work. It is best to avoid very wet, sloppy mixtures at all times because they do not hold together in handling. The larger pieces of aggregate sink in the mass. Such concrete will be of poor quality.

Correcting Trial Mixture

If the trial mixture is not workable, it is necessary to change the amounts of aggregate used in the concrete.



Concrete swimming pools give hours of pleasure during hot days and add to healthful living.

Under no circumstances change the total amount of water specified for the particular class of work.

The trial batch of 1 part cement to 2½ parts sand and 3½ parts coarse aggregate (1: 2½: 3½ mix), for example, may be too stiff or too wet or may lack smoothness and workability.

If the trial proportion gives a mixture that is too wet, add small amounts of sand and coarse aggregate in the proportion of 2½ parts sand and 3½ parts coarse aggregate until the right workability is obtained.

If it is necessary to use more sand than is shown in the trial proportions given in Table 1—for instance, an extra ½ cu.ft. of wet sand—it is important to deduct the moisture carried by this additional sand. For the trial proportion of 1: 2½: 3½, 5 gal. of water is required to mix with each sack of cement when the sand is wet. With the addition of ½ cu.ft. more sand, making the mix 1: 3: 3½, only 4¾ gal. of water is added at the mixer in following batches.

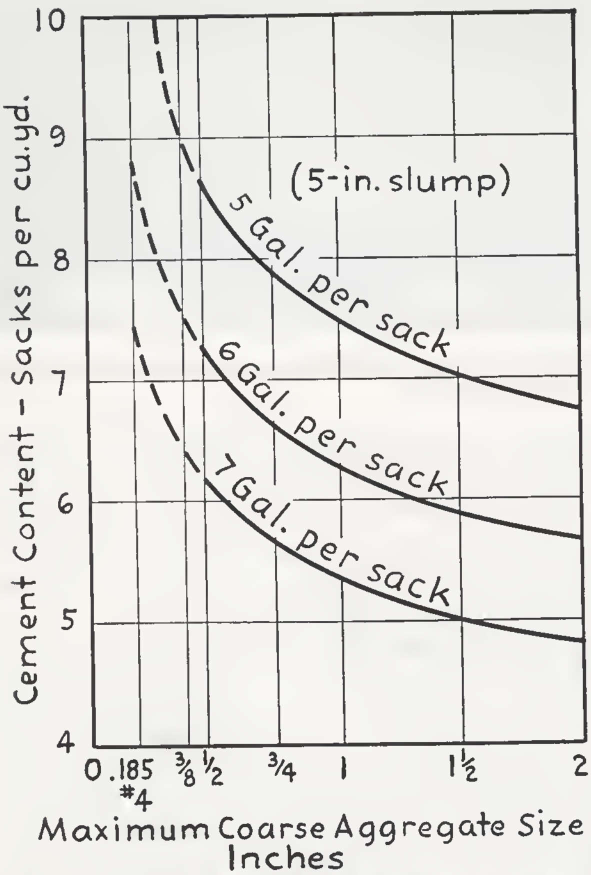
If the concrete is too stiff and appears crumbly, succeeding batches are mixed with less aggregate. Usually slightly less coarse material will give the required workability.

Proportioning for Economy

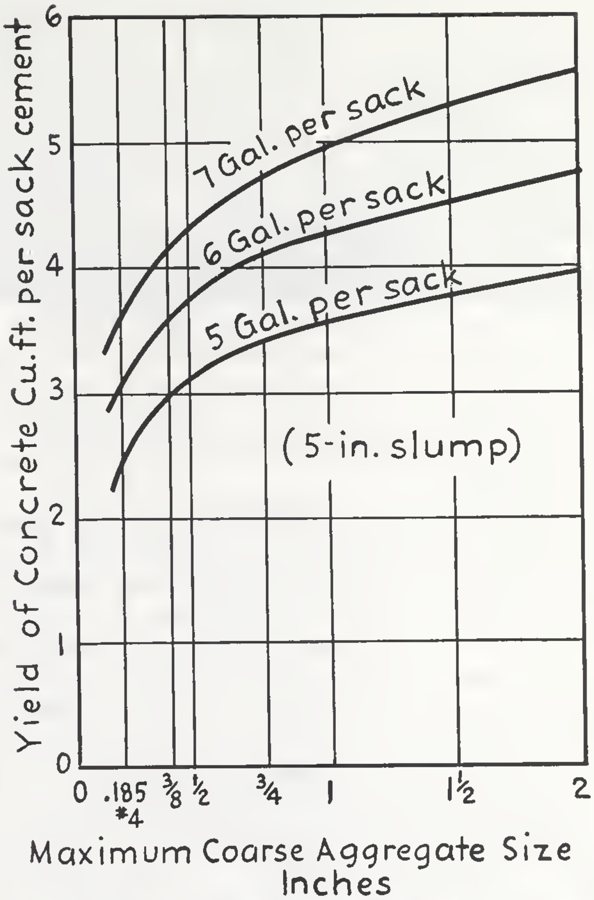
Adherence to the water-cement ratio method will control quality but may not result in economical concrete. In small jobs there may be only a negligible difference in cost; but as the quantity involved increases, it becomes increasingly important to proportion for economy.

To secure a dense, impervious concrete, it is essential that all surfaces of aggregates be thoroughly coated

Left—A concrete mixture in which there is not sufficient cement-sand mortar to fill the spaces between the pebbles. Such a mixture will be hard to work and will result in rough, honeycombed surfaces. Center—A concrete mixture which contains correct amount of cement-sand mortar. With light troweling, all spaces between pebbles are filled with mortar. This is a good, workable mixture. Right—A concrete mixture in which there is an excess of cement-sand mortar. While such a mixture is plastic and workable and will produce smooth surfaces, the yield of concrete will be low. Such concrete is likely to be porous.



Curves showing sacks of portland cement required to produce 1 cu.yd. of concrete using 5 gal., 6 gal. and 7 gal. of water per sack of cement with various maximum-size coarse aggregates. Values shown on solid lines are based on data from "Proposed Recommended Practice for the Design of Concrete Mixes", *Journal* of the American Concrete Institute, November 1943. Values shown by broken lines are interpreted from Portland Cement Association laboratory tests.



Volume of concrete (cubic feet) produced from one sack of portland cement (using various maximum-size coarse aggregates and 5 gal. 6 gal. and 7 gal. of water per sack of cement).

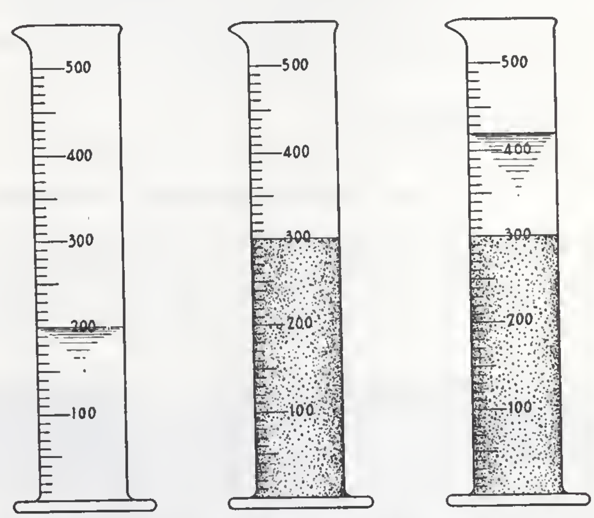
with the cement paste and all voids filled. It readily can be seen that to secure economical concrete with as little cement as possible, it is necessary to select an aggregate with as low surface area and as few voids or air spaces as practicable. Aggregates vary widely in the size of the individual particles and the gradation or proportion of each size in the mixture. Gradation affects both the percentage of voids and the total surface area. The "yield" or quantity of a given quality of concrete which can be obtained from a sack of cement will vary accordingly. It should be remembered that the aggregate is the cheap ingredient.

Voids in Sand and Gravel (*Demonstration No. 9*). The percentage of voids in any given aggregate and the variation with change in size can be determined easily.

1. Fill a 500-cc. graduate to the 200-cc. mark with water. Fill a second 500-cc. graduate to the 300-cc. mark with bank-run aggregate. Pour the bank run into the water. Note that 200 cc. of water plus 300 cc. of bank run fall considerably short of making a total of 500 cc. It is essential that the aggregate be poured into the water rather than the water into the aggregate. Why? 500 minus the volume of mixed water and aggregate equals the cubic centimeters of voids (air spaces) in the original aggregate:

$$\frac{\text{cc. voids}}{\text{cc. aggregate}} \times 100 = \text{percentage of voids.}$$

2. Screen the remaining bank run, and repeat this test with the coarse aggregate and with the fine



For dense and economical concrete the aggregate should have a low percentage of voids. See Demonstration No. 9.

aggregate. Tabulate all results.

3. Take approximately 1,000 cc. of fine aggregate and screen, in turn, through the Nos. 8, 14, 28, 48 and 100 sieves, keeping separate the material retained on each screen.

If Nos. 6, 10 and 20 sieves are available, it would be preferable to use Nos. 6, 8, 10, 14 and 20 instead of Nos. 8, 14, 28, 48 and 100, as indicated above. When screening sand which is composed of mixed sizes, it is obvious that particles in any batch will vary in size from that barely passing the coarser sieve such as the No. 4 to particles approximately half the diameter which will almost pass the No. 8. Using the intermediate sizes, Nos. 6, 10 and 20, results in samples more nearly uniform in size. This in turn results in more nearly uniform percentages of voids in the test. Still more satisfactory results would be obtained by the use of small marbles or shot which were uniform in size within the batch but varied in size from one batch to another.

It will be noted that in all specimens, the particles approach the spherical and are approximately uniform in size. The average diameter is reduced by one-half from one specimen to the next. Test each one as indicated above and tabulate the results as suggested by the following:

	1	2	3	4	5
	cc. water	cc. aggregate	cc. agg. plus water 1+2	cc. voids	per cent voids
Passing 4 retained 8					
Passing 8 retained 14					
Passing 14 retained 28					
Passing 28 retained 48					
Passing 48 retained 100					
Bank run					
Coarse aggregate					
Fine aggregate					

Note the uniformity in percentage of voids in all cases of particles uniform in size. Why? Compare the percentage of voids with that obtained with the sample of bank run.

Cubes ($v=d^3$) could be placed with no voids.

Spheres ($v=\frac{\pi d^3}{6}$) placed within the cubes would leave a uniform percentage of voids regardless of size of sphere.

Volume of cube minus volume of sphere:

$$d^3-\frac{\pi d^3}{6}=d^3\left(1-\frac{\pi}{6}\right)=d^3\,(1-.524)=.476d^3$$

or 47.6 per cent of total volume of cube.

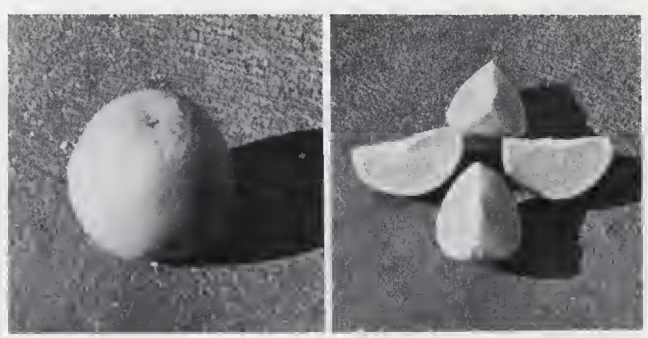
Spheres arranged at random fill the space more completely. The best arrangement would still leave 35 per cent voids regardless of the size of balls. Sand particles of uniform size which are not spherical and not perfectly arranged usually run somewhat higher.

4. Take measured volumes of various sizes and remix. Show that the total volume is considerably less than the sum of the volumes measured independently. Assuming that there should be a sufficient quantity of each size of aggregate to fill the voids in the next larger size, what mixture theoretically would give the lowest percentage of voids? Make such a mixture and determine the actual percentage of voids. Clay has a higher percentage of voids than most sands. Why?

Surface Area of Aggregate (*Demonstration No. 10*). The quantity of a given quality of concrete which can be obtained from a sack of cement decreases as the surface area of the aggregate increases, since there is a limit to the total surface which can be coated with a given quantity of paste.

Is there a change in surface area as the size of individual grains varies? Which has greater surface, 100 lb. of coarse aggregate or the same weight of fine?

If the size of a cube is of a length d, the area of the surface is $6d^2$. The surface of a sphere of diameter d is πd^2. The surface of a 1-in. cube is $6\times1\times1$ or 6 sq.in. Since eight ½-in. cubes are equal in volume to one 1-in. cube, the surface area of eight ½-in. cubes is 8×1.5 or 12 sq.in., which is twice the area of the 1-in. cube. Likewise, with the sphere, the area of a 1-in. sphere is $\pi(1)^2$, or 3.14 sq.in. The surface of a ½-in. sphere is $\pi(\frac{1}{2})^2=\frac{\pi}{4}$. Again, since eight ½-in. spheres are needed to equal one 1-in. sphere in volume, the surface area of an equal volume of ½-in. spheres is $8\times\frac{\pi}{4}=2\pi$, or 6.28 sq.in. Thus, it will be noted that each time the size of particle is reduced by one-half, the surface area is doubled. The surface area of that passing the No. 8 and retained on No. 14 is double that of the same volume passing 4 and retained on 8. That passing No. 14 and retained on No. 28 has 4 times the surface



The volume of the whole orange (left) and that of the divided orange is the same, but the divided orange has more surface area.

In general, the stiffer the mix, the more economical the concrete. All five of the above specimens were made with identical quantities of water and cement. The amount of aggregate in each case varied. Specimen No. 5 contains the least aggregate, and No. 1 contains the most. Therefore, No. 1 is the most economical mix.

area of that passing 4 and retained on 8, etc.

From this demonstration it is apparent that in a given volume of aggregate the larger the particles, the smaller the total surface area to cover.

This can be shown graphically in the following manner: Using the standard sieves, screen out about a pint of each size of aggregate—that is, sand passing the No. 4 sieve but retained on the No. 8; sand passing the No. 8 and retained on the No. 14. Take 1,000 grams of dry aggregate, each size in turn, 600 grams of cement and 300 grams of water. Mix aggregate and cement and add water. Mix thoroughly and place in slump cone, tamping 25 strokes with the pointed end of a ⅜-in. rod. This cone should be made of the same proportions as the one shown on page 25 but only 4 in. high. Remove cone and observe the slump. Repeat in turn with each size of aggregate. It will be noted that although the mixture with the aggregate passing the No. 4 but retained on the No. 8 sieve is decidedly sloppy, each succeeding mixture appears drier. That made from sand passing the No. 100 sieve will scarcely hold together. Why? From the preceding experiment, it will be remembered that the percentage of voids is equal in each case. This experiment also may be varied by taking 600 grams of cement and 300 grams of water, mixing these into a paste and adding sufficient aggregate of each size in turn to get a 2-in. slump. Compare the total amount of mixture obtained in each case. Now take a sample of mixed aggregate, preferably one which gave a low percentage of voids, and compare the results with those just obtained.

In the preceding discussion, it was shown that it is desirable to have a well-graded aggregate to reduce the percentage of voids. By combining these two principles relating to voids and surface area, one concludes that the most desirable aggregate would be well graded up to sizes as large as can be used effectively. The practical significance of this is illustrated clearly in the graph on page 22, which shows the variation in cement required per cubic yard of concrete when well-graded aggregates are used, but with different maximum size of aggregate. The economy of the larger sizes is apparent.

Such an aggregate will have the desirable combination of low percentage of voids and low surface area. Most natural aggregates run too fine to be economical. However, the amount of coarse aggregate which can be used is often limited by the amount of exposed surface of the concrete rather than by the economy of mixture. Coarse aggregate must be forced back from the surface. Small thin sections such as fence posts or watering tanks with large surface area in proportion to volume need reduced size and amount of coarse aggregate.

Selection of Aggregate Combination

In determining the proportions of materials, it is desirable to arrive at those proportions which will give the most economical results consistent with proper placing. The relative proportions of fine and coarse aggregates and the total amount of aggregate that can be used with fixed amounts of cement and water will depend not only on the consistency of concrete required but also on the grading of each aggregate. The more aggregate mixed with the cement paste, the more concrete will be produced. The stiff mix contains the largest amount of aggregate and is ordinarily the most economical from the standpoint of materials.

The shrinkage of concrete during the curing process is approximately proportional to the amount of water used in making it. A mixture carefully proportioned to require a minimum of cement paste offers the additional advantage of making concrete which will shrink less than if more paste were used.

It is poor economy, however, to place a mix that is so stiff that it requires an excessive amount of labor for tamping and spading. Added labor cost in placing and finishing, may offset what is saved in materials.

The Slump Test

The slump test may be used as a rough measure of the consistency of concrete—that is, the degree of wetness of concrete, such as stiff, medium or wet. This test is not to be considered as an exact measure of workability, and it should not be used to compare mixes of entirely different proportions or of different kinds of aggregates. Changes in the slump indicate changes in grading or proportion of the aggregates or in the water content, produced by changes in moisture content of the sand. Correction should be made immediately to get the proper consistency by changing amounts and proportion of sand and coarse aggregate, care being taken not to change the total amount of water specified for mixing with each sack of cement.

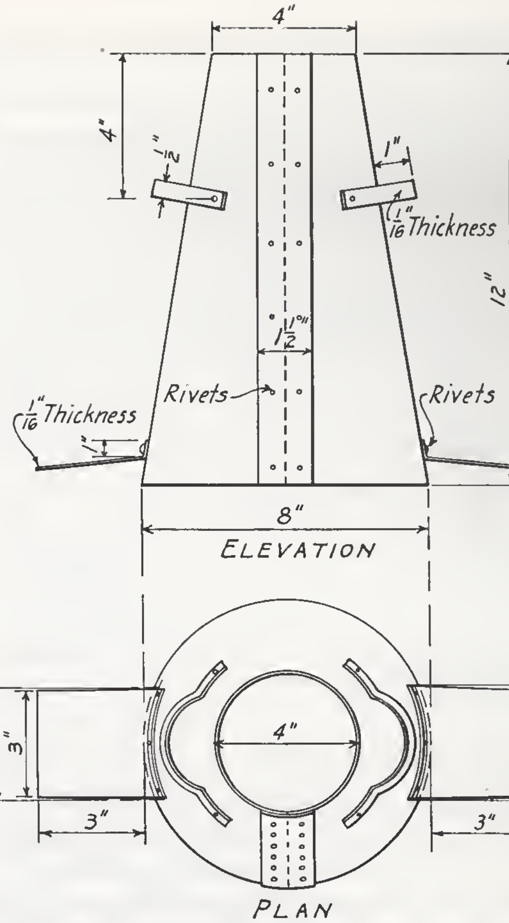
To avoid mixes that are too stiff or too wet, slumps falling within the limits given in Table 3 are recommended. This table lists a few kinds of structures as typical examples for each range of slumps. The slump test is especially useful in colored concrete work.

TABLE 3—RECOMMENDED SLUMPS FOR CONCRETE

TYPE OF STRUCTURE	Slump in inches	
	Minimum	Maximum
Massive sections; pavements and floors laid on ground.	1	4
Heavy slabs, beams or walls; tank walls; posts.	3	6
Thin walls and columns; ordinary slabs or beams; vases and garden furniture.	4	8

In making the slump test, the test specimen is made in a mold of No. 16-gage galvanized metal in the form shown in the diagram at the right, the diameter at the base being 8 in., at the top, 4 in., and the height being 12 in. The base and top are open. The mold is provided with foot pieces and handles as shown.

When the slump test is made, the sample is taken immediately after the concrete has been discharged from the mixer. The mold is placed on a flat surface, such as a smooth plank or a slab of concrete, and is held firmly in place by standing on the foot pieces while

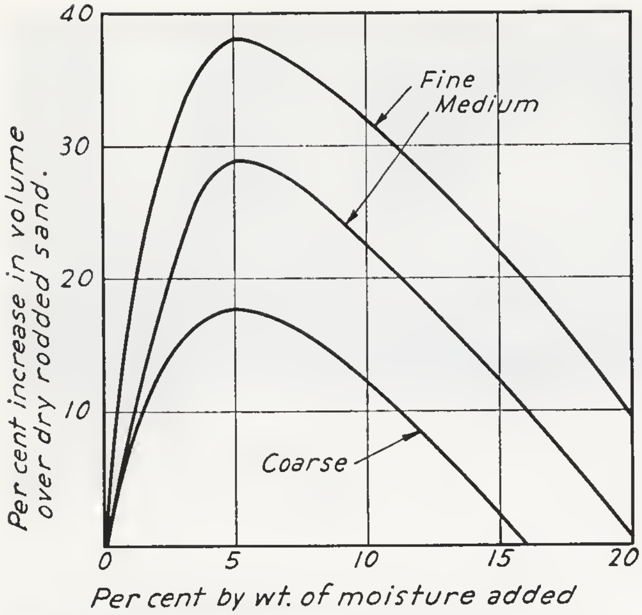


Design of cone used in making slump test.

filling it with concrete. The mold is filled to about one-fourth its height with concrete, which then is puddled with 25 strokes of a ⅝-in. rod, bullet pointed at the lower end. The filling is completed in two more layers, rodding each 25 times without passing the rod through the layer below, and the top struck off so that the mold is exactly filled. The mold is removed by being raised vertically immediately after being filled.

The slump of the concrete is measured, as shown in the photograph below, immediately after the cone is removed. For example, if the top of the slumped pile is 4 in. lower than the top of the cone, the slump for this concrete is 4 in.; if 6 in. lower, the slump is 6 in., etc.

The slump test shows consistency of concrete. Slump is measured from rod laid across the top of the slump cone. Cone in center illustrates slump of medium wet concrete mixture. Cone at right illustrates slump of stiff concrete.



Effect of moisture in bulking of sand.

Moisture and Bulking of Sand

When moisture is added to dry sand, films of water are formed on the surfaces of the particles, fluffing them apart. This causes an increase in the volume, when measured in the loose condition, much greater than the volume of water added, so that a given volume of damp sand may be the equivalent of a much smaller volume of dry sand. This bulking increases rapidly with increases in moisture content until the moisture is about 6 per cent by weight when the bulking may be as much as 20 to 30 per cent. Further additions of water tend to flood or pack the sand, decreasing the amount of bulking. When the sand is completely inundated the volume is approximately the same as when measured dry and loose. The finer the material the more it will bulk for a given moisture content. The size of the measure and the method of filling also affect bulking, which should be evaluated for each job. Coarse aggregates are little affected in volume by moisture.

Bulking of Sand (*Demonstration No. 11*). The following demonstration will help to show the effect of moisture upon bulking:

1. Fill a beaker, small can or other container with dry sand without shaking or tamping; strike off excess with straightedge and weigh.
2. Pour sand out on flat nonabsorptive surface; add 2 per cent of water, by weight; mix thoroughly and pour back into the beaker. Care should be taken to fill the container the same way as before; strike off excess, as before, and weigh.
3. Continue adding increments of water until the sand will not retain more. Tabulate results as below and plot on coordinate ruled paper, using per cent of dry weight as ordinates and increments of water added as abscissas.

	Weight grams	Per cent dry weight
Dry		100
2 per cent water		
4 per cent water		
6 per cent water		
8 per cent water		
10 per cent water		

This little test illustrates quite effectively that volume measurements of aggregate may be far from accurate. Results may be plotted on the figure at the left which shows average results from laboratory tests.

Making Allowance for Bulking on the Job

Failure to allow for this bulking increases the cost of the concrete, but of even greater importance is the effect on the mixture; undersanded mixes which are harsh and difficult to place often result. An example will illustrate. If the medium sand shown in the diagram is used and it contains 5 per cent moisture, it is seen that the bulking is 29 per cent. This means that 1 cu.ft. of dry sand occupies 1.29 cu.ft. in the damp condition. Therefore, 1 cu.ft. of the damp sand contains only $\frac{1}{1.29} = 0.775$ cu.ft. of dry sand. If the mix to be measured is 1:2:4 by volume and no correction is made for bulking, instead of 2 cu.ft. of sand the actual dry sand measured will be $\frac{1}{1.29} \times 2 = 1.55$ cu.ft. The mix will then be 1:1.55:4 in terms of dry sand. This reduction in the ratio of sand causes a reduction in the quantity of concrete produced with each sack of portland cement and in most cases there will be insuffi-

Concrete sewage treatment plants, such as this one, safely dispose of sewage from cities.

cient fine material for the amount of coarse material to give a workable mixture.

In this example it requircs 1.29 cu.ft. of damp sand to give 1 cu.ft. of dry sand. Therefore, $1.29 \times 2 = 2.58$ cu.ft. of damp sand should be measured for each sack of cement, giving a corrected field mix of 1:2.58:4.

Workability

The workability of concrete may vary with the selection and mixture of aggregates. In general, the percentage of sand should be less whcn it is finc tban when it is coarse. Thcre are certain objcctions, however, to using very fine sand such as plaster sand or beach sand. Combined witb coarse aggregate, it often produces a mixture in which it is difficult to avoid segregation. The finer the sand, the more likely it is made up predominantly of onc or two sizes. It is, therefore, generally accepted that coarsely graded sands are most desirable. All sands must contain sufficient fine particles to assist the cement in producing good workability. Specifications usually permit a rather wide range as indicated in Demonstration No. 5.

It is desirable, then, to select that combination of sand and coarse aggregatc which will produce the largest amount of plastic, workable concrete from a given amount of paste. Experience has shown that for average sand and coarse aggregate on average jobs, this proportion is approximately 40 per cent sand and 60 per cent coarse aggregate. Gencrally, a slightly oversanded mix is the most satisfactory.

The suggested proportions given in Table 1 are for use only in trial batches. Each of these proportions may need to be corrected to get thc best yield and the desired workability. Mixtures of different consistencies are sbown on page 21. For foundations, footings, walls, pavements and similar work, a stiff consistency is recommended. A moderately wet mix is suitable for tbin sections of concrete.

Estimating Quantities of Materials

Information that will be helpful in estimating approximate quantities of materials required in concrete is given in Table 1 and in the figure on page 22. The quantities may be determined accurately by making use of tbe fact that the volume of concrete produced by any combination of materials, as long as the concrete is plastic, is equal to the sum of the absolute volume of the cement plus the absolute volume of the aggregate plus tbe volume of water. The absolute volume of a loose material is tbe actual total volumc of solid matter in all the particles. This can be computed from the wcight per unit volume and the apparent specific gravity as follows:

$$\text{Absolute volume} = \frac{\text{unit weight}}{\text{apparent specific gravity} \times \text{unit weight of water (62.5 lb. per cubic foot)}}$$

in whicb the unit weight is based on surface dry aggregate.

The metbod can best be illustrated by an example. Suppose tbe concrcte batch consists of 1 sack of cement (94 lb.), 2.2 cu.ft. of dry fine aggregate weighing 110 lb. per cubic foot and 3.6 cu.ft. of dry coarse aggregate weigbing 100 lb. per cubic foot and is to be mixed witb a water-cement ratio of 7 gal. pcr sack. The apparent specific gravity of the cement is usually about 3.1 and of the more common aggregates about 2.65. The volume of concrete produced by the above mix is calculated as follows:

$$\text{Cement} = 1 \text{ cu.ft.} \times \frac{94}{3.1 \times 62.5} = .49 \text{ cu.ft. abs. vol.}$$

$$\text{Fine aggregate} = 2.2 \text{ cu.ft.} \times \frac{110}{2.65 \times 62.5} = 1.46 \text{ cu.ft. abs. vol.}$$

$$\text{Coarse aggregate} = 3.6 \text{ cu.ft.} \times \frac{100}{2.65 \times 62.5} = 2.17 \text{ cu.ft. abs. vol.}$$

$$\text{Volume of water} = \frac{7.0}{7.5} = .93 \text{ cu.ft. abs. vol.}$$

Total volume
of concrete produced = 5.05 cu.ft.

Thus 1 sack of cement produces 5.05 cu.ft., neglecting absorption or losses in manipulation. Cement required for 1 cu.yd. of concrete is, then, $\frac{27}{5.05} = 5.34$ sacks or 1.34 barrels. The quantities of fine and coarse aggregate required can be found from a simple computation based on the number of cubic feet used with each sack of cement; thus, for the fine aggregate

Winter feed is stored in concrete silos on thousands of farms throughout the country.

$\frac{5.34\times2.2}{27}=.44$ cu.yd. and for the coarse aggregate $\frac{5.34\times3.6}{27}=.71$ cu.yd.

For unusual materials such as blast furnace slag and special lightweight aggregates, the exact apparent specific gravities should be used. It will be found that, for the purpose of estimating quantities, the average value of 2.65, given previously, will be sufficiently accurate for sand, gravel and limestone. The average value for granite is about 2.70 and for trap rock about 2.95.

Summary

From the discussion in this chapter it will be observed that, other factors being equal, adherence to the water-cement ratio will control the quality of the concrete. Economy can be secured by controlling the gradation of the aggregate, using as large material as can be handled on the job at hand and a proper distribution of the various sizes.

Formerly it was customary to specify the quantities of cement, fine aggregate and coarse aggregate as 1:2:4, meaning 1 part cement, 2 parts fine aggregate, and 4 parts coarse aggregate.

This method may fail to assure satisfactory results for the following reasons:

1. It does not specify the quantity of mixing water which is so essential to the determination of strength and watertightness.
2. It does not consider the gradation of aggregate with the accompanying variation of voids and surface area which may affect the yield.
3. It does not allow for variations in volume resulting from the tendency toward the bulking of moist sands.
4. It is often taken as the equivalent of 1:6. That is, if the user desires not to screen the bank run and remix according to recommendations, he may reason that 2 cu.ft. of fine aggregate, plus 4 cu.ft. of coarse aggregate, will equal 6 cu.ft. of bank run. This is not the case. In the first place, bank run is usually short in coarse aggregate. In the second place, the fine aggregate will fill the voids in the coarse aggregate and the total volume will be only about 5.1 cu.ft. The use of the water-cement ratio method will automatically compensate for these variations and insure, with proper subsequent treatment, concrete of a predetermined quality. Economy can be secured by proper gradation of the aggregate.

A safe, sturdy, all-concrete stadium. Note the cantilevered concrete roof.

Questions

1. What effect has the quantity of mixing water upon the quality of concrete?
2. Does the amount of aggregate added, or the proportion of fine to coarse aggregate affect the strength of the concrete?
3. What is the basis of the design of concrete mixtures for strength?
4. State the water-cement ratio strength law.
5. How much water would you use per sack of cement in making a watertight stock tank?
6. As applied to concrete mixtures, what is meant by consistency? Plasticity? Workability?
7. Is a workable mix the same for all types of construction?
8. Does a high compressive strength always indicate that the concrete possesses other desirable qualities to a high degree?
9. What are the principal requirements for durable concrete?
10. Is it necessary to consider the water present in aggregates?
11. Can surface water carried by aggregates be estimated for average conditions? Explain.
12. How can the correct proportions of water, cement, sand and pebbles to use in a mixture be determined?
13. What is meant by a trial mixture? How is it used?
14. How would you decide on the amount of sand and gravel to use?
15. Should the ratio of water to cement be changed after a trial mixture?
16. Why are dry or overwet mixes to be avoided from the standpoint of placing concrete?
17. Where mixes are to be designed for a given water-cement ratio, is the grading of the aggregate an important consideration?
18. Why is bank-run gravel seldom suitable for concrete work?
19. Is a 1:2:3 mix the same as a 1:5 bank-run gravel mix? Why?
20. How can bank-run gravel be used?
21. Does the relative proportion of fine and coarse affect the yield, that is, amount of concrete that can be obtained with a sack of cement and a fixed proportion of water? Why?
22. How is the slump test made?

CHAPTER 4

FIELD CONTROL

Field control includes:
- Selection of materials
- Measurement of materials
- Mixing the materials
- Placing
- Finishing
- Curing

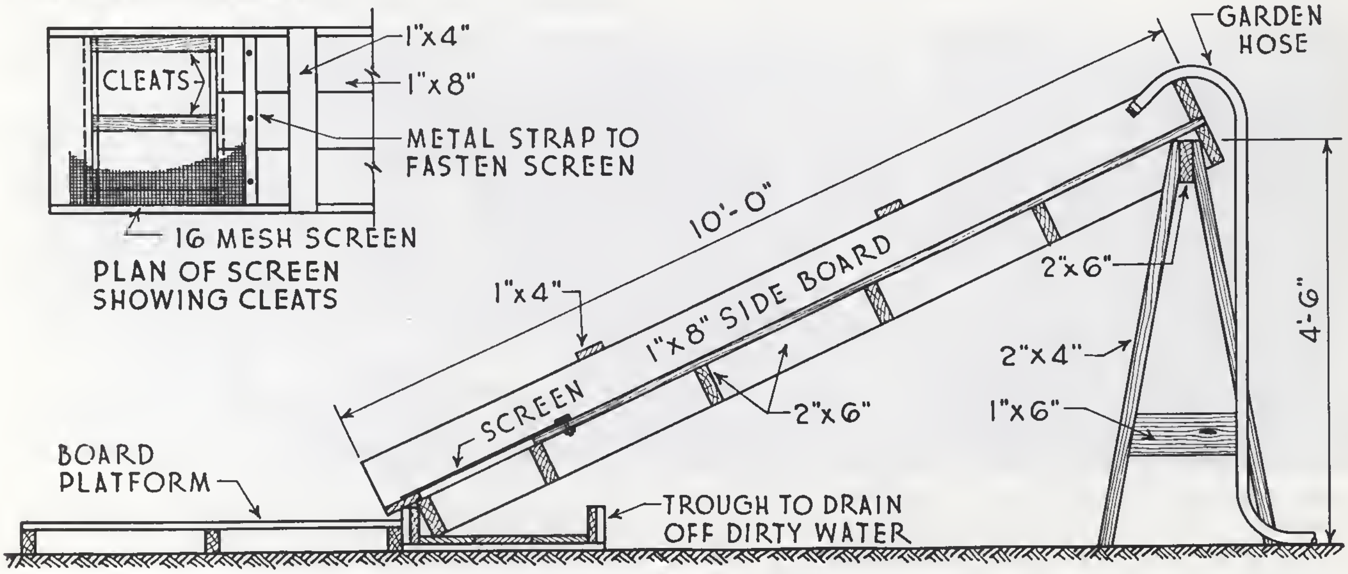
Selection of Materials

Before concreting operations have started, as well as during the progress of the work, it is desirable to make certain tests of the materials. Some of these relate to the suitability of the aggregates for the work, and others are necessary to control the concrete properly so that uniform batches are produced. Adjustments can be made in the mix for variations in materials.

In all tests it is important that the samples of aggregates be representative of the materials used on the job. Reducing large field samples to small quantities for individual tests should be done with care so that the final sample will be representative. This may be done by the quartering method. The aggregate sample, thoroughly mixed, is spread on a piece of canvas in an even layer 3 or 4 in. thick. It is then divided into four equal parts and two opposite parts discarded. This process is repeated until the desired size of sample remains. Several casily made tests will give a good indication of the quality of the aggregate as well as its gradation. These, as described in the chapter on *Materials*, are:

The "quartering" method is used to get representative samples of aggregates for testing.

Simple device for washing aggregates.



1. Color test for presence of organic materials.
2. Silt test.
3. Percentage of coarse and fine aggregatc in hank run.
4. Gradation of the fine aggregate.

Sand or gravel containing injurious amounts of silt or organic matter should he washed. A simple washing device is illustrated on page 29. The materials to be washed are piled on the higher end. Water is supplied by a garden hose, pail or other convenient means.

As the materials are washed down the incline, silt, dust and organic matter separate out and are carried away in the water. It is a good plan to run check tcsts to see whether washing has heen done thoroughly.

Measurement of Materials

All materials including water should be measured accurately to insure production of uniform hatches of concrete of the quality desired. Nothing makes a good joh more difficult to ohtain than to have one batch mixed properly, the next one sloppy, another one harsh, and so forth during the progress of the work. Aggregates can be measured easily hy using a bottomless box made to hold exactly 1 cu.ft., 2 cu.ft. or any other volume desired. To measure the materials the box is placed on the mixing platform and filled. When the required amount of material has been placed in it, the box is lifted and the material remains on the platform. Each sack of cement contains 1 cu.ft.

Pails are often used for proportioning materials. For example, a 1:2:3 batch of concrete could be measured hy using 1 pail of portland cement, 2 pails of sand and 3 pails of gravel or crushed stone.

Measuring can he donc with shovels, ohserving carefully the number of shovelfuls taken in handling exactly 1 cu.ft. of material. This is done by counting the number of shovelfuls of each material required to fill a cubic foot box or a cement sack. This test should he made at least once each day, particularly if new loads of material are delivered on the job.

If measuring is done with wheelbarrows, each harrow should be marked on the inside for 1 cu.ft., 2 cu.ft., etc. This marking can be done by dumping a cubic-foot hox or a cement sack full of material in the harrow, leveling and making a mark at that level. This can be repeated with another cuhic foot of material, etc., until the barrow is calibrated. All measurements by volume of moist fine aggregate should be corrected for bulking. Measurement by weight has many advantages over measurement by volume. It is more nearly accurate, produces better uniformity from batch to hatch, and is easily adjusted for necessary changes in proportions and eliminates the problem of correcting for bulking of sand.

Suggested trial mixes are given in Tahle 4. The numher of pounds of sand and coarse aggregate may have to he adjustcd to get a mushy, workahle mix.

TABLE 4—SUGGESTED TRIAL MIXES FOR CONCRETE USING COARSE SAND

Water per bag of cement	Max. size aggregate (in.)	Pounds of aggregate	
		Sand	Coarse aggregate
5 gal.	¾	185	210
	1	175	240
	1½	170	280
	2	170	315
6 gal.	¾	245	255
	1	225	285
	1½	225	335
	2	220	380
7 gal.	¾	300	290
	1	280	330
	1½	270	385
	2	280	435

It is necessary to maintain accurate measurement of mixing water throughout the job.

Many concrete mixers, now equipped with tanks and measuring devices, can he set to deliver any number of gallons of water into the mixer drum as specified for the work at hand. It is necessary to check water-measuring equipment regularly and to see that valves are tight to insure accuracy. An ordinary 12-qt. galvanized pail, marked off in gallons, half gallons and quarter gallons, is used to measure water when mixers are not equipped with measuring devices. A pail kept at the mixer for this purpose is useful in measuring water from a barrel.

Mixing the Materials

Although first-class concrete can he mixed hy hand, machine mixing is preferred hecause it results in more thoroughly mixed and uniform batches. Whichever way mixing is done, it should continue until every piece of gravel or stone is completely coated with a thoroughly mixed mortar of sand and cement.

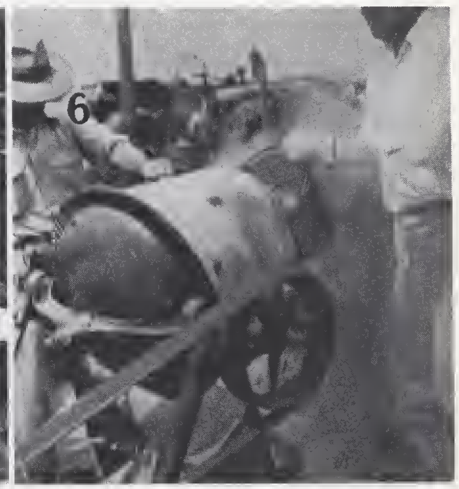
Practically all of the standard batch-type machine mixers on the market will give satisfactory service. In case one person may not have sufficient work to justify the purchase of a mixer, it is often possihle to rent a mixer or for several to share the expense of huying one.

With a batch-type machine mixer it is recommended that mixing continue for at least one minute and preferahly for two minutes after all materials, including water, are placed in the mixer drum.

Tests made with mixers under joh conditions show a rapid increase in strength in the concrete as the mixing time is increased from 15 seconds up to about two minutes. For example, concrete mixed for about two minutes in a batch-type machine mixer is 20 to 35 per

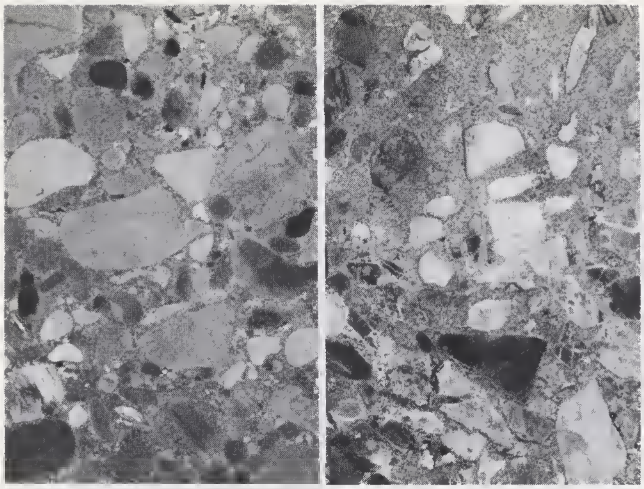
Steps in making trial batch of concrete using $1\frac{1}{2}$-in. gravel and 6-gal. mix ($\frac{1}{5}$-sack batch mixer).

1. Test sand for moisture as shown on page 26. If wet, use 5 gal. of water per sack of cement (Table 1). 2. Measure water. Since mixer holds $\frac{1}{5}$ sack batch, use $\frac{1}{5}$ of 5 gal. or 1 gal. A simple method is to measure 4 qt. (1 gal.) into a pail and then mark at waterline. Thereafter fill to this mark. 3. Measure cement. Use $1\frac{1}{2}$ vol. of cement for 1 vol. water (Table 1). Since 4 qt. of water is used, $1\frac{1}{2} \times 4$ or 6 qt. of cement is needed. Measure 6 qt. of cement into a pail, level it off and mark at top edge of cement. Thereafter fill to this mark.



4. Ready for mixing. First put water (4 qt.) into mixer. 5. Next add part of gravel. Adding gravel to water before cement is added prevents cement from sticking to drum. 6. Add measured amount of cement (6 qt.).

7. Then add sand and gravel in proper proportions until a mushy workable mix is obtained. In mixing a trial batch try the proportions given on page 18. 8. Mix for about 2 minutes after all materials have been added. Run mixer at speed recommended by manufacturer. 9. After all particles are coated with cement paste (about 2-minute mix) dump out concrete.



Sections cut through 6x12-in. concrete cylinders showing good and bad distribution of coarse aggregates. On the left, coarse particles are distributed throughout the mass; at the right, coarse aggregate has settled as a result of too sloppy a mixture, leaving fine particles at the surface.

cent stronger than the same concrete mixed only 15 seconds. Thorough mixing also results in more uniform concrete.

Small changes in the speed of the mixer have little effect, because thoroughness of mixing is governed largely by the time of mixing and not the rate of rotation of the mixer drum. Loading the mixer above its rated capacity is not recommended, as it prevents thorough mixing. If increased output is needed, it is best obtained by using a larger mixer or additional mixers instead of speeding up or overloading equipment.

Good judgment is necessary to secure concrete of proper consistency. The mixture appears drier in the mixer than it does after being placed. If the quantity involved is small and one is not particularly concerned with economy, a simple procedure is as follows:

1. Set mixer in motion.
2. Add the specified amount of water.
3. Add a small quantity of aggregate.
4. Add the amount of cement necessary according to the proper water-cement ratio.
5. Add aggregate until desired workability has been obtained. Aggregate should be placed in the mixer slowly until concrete is of the proper consistency.

The procedure illustrated on page 31 with due consideration to proportioning of fine and coarse materials will also assure economy.

At the end of each day's run, or whenever concreting is stopped for more than an hour, the mixer should be thoroughly washed and cleaned out. This can be done easily by scouring with water and pebbles. Any caked concrete adhering to the drum or blades should be broken loose and removed.

This is usual procedure in mixing concrete by hand: The measured quantity of sand is spread out evenly on the platform. On this the required amount of cement is dumped and evenly distributed. The cement and sand are then turned over thoroughly with No. 2 square pointed shovels enough times to produce a mass of uniform color, free from streaks of brown and gery. Such streaks indicate that the sand and cement have not been mixed thoroughly.

This mixture is spread out evenly over the platform and the required quantity of gravel or crushed stone is then measured and spread in a layer on top. The materials are again mixed by turning with shovels until the coarse aggregate has been uniformly distributed throughout the mixture of cement and sand. At least three turnings are necessary.

A depression or hollow is then formed in the center of the pile and the proper amount of water added slowly while the materials are turned in toward the center with square pointed shovels. This turning is continued until the cement, sand and gravel or crushed stone have been thoroughly and uniformly combined and the desired workability and smoothness obtained.

Placing

Methods used to move concrete depend largely upon job conditions. On small jobs, wheelbarrows are the usual means of transportation from the mixer to the forms. On larger jobs, buggies and chutes are commonly used.

When using barrows or buggies, care is required to prevent segregation of the coarse from the fine particles while the concrete is being moved. Segregation is likely to occur when concrete is handled over rough ground or runways. A rather stiff consistency usually is required to prevent segregation.

Concrete should be placed in the forms as soon as

Spading concrete in forms forces coarse aggregates back from the face and produces a smooth surface on the finished wall.

Depositing concrete evenly in 6-in. layers at all points around the wall helps prevent segregation of coarse and fine aggregates.

possible and in no case more than 45 minutes after mixing. Remove all debris and thoroughly wet or oil the forms before placing concrete.

Deposit the concrete in level layers, not more than 12 in. deep, tamping and spading just enough to make it settle thoroughly and produce a dense mass. Working of the concrete next to the forms insures an even, dense surface when forms are removed. Water should not stand on the concrete surface after it is placed.

If the mixture becomes sloppy as the forms are filled, because water is forced out of the lower layers of concrete, stiffer mixtures should be used.

At the end of a day's run or where the work has to stop long enough for the concrete to begin hardening, roughen the top surface just before it hardens to provide a good bond for the next layer of concrete. Just before resuming concreting, clean the roughened surface and then brush with a cement-water paste of a thick, creamy consistency. This paste is applied in a thick brush coat only a few feet ahead of the concreting operation so that it does not have a chance to dry before it is covered with concrete.

This precaution to get a good bond between different layers of concrete is very important, particularly if the concrete construction is to be watertight.

It is just as important to prevent segregation in the forms as it is when transporting the concrete from the mixer to the forms. Depositing the concrete uniformly around the forms where it is to be used rather than placing it at a few points and dragging it or causing it to flow where needed helps prevent segregation and honeycombing.

Further care is required to work the concrete into corners and angles of forms and, in reinforced work, around reinforcement.

Finishing

The following general information on finishing applies to the average concrete job. For colored concrete and special surface finishes, see Chapter 7.

The concrete is struck off or leveled carefully just after it is placed in the forms. This removes all humps and hollows, leaving a true, even surface.

The time of finishing is important. It should be delayed until the surface is quite stiff but still workable. If a small quantity of surface water appears it should be allowed to evaporate before finishing. If there is considerable water, it should be removed with a broom, belt, float or other convenient means. It is never good practice to sprinkle dry cement or a mixture of cement and fine aggregate on concrete to take up surface water; such fine material forms a layer on the surface that is likely to dust or develop numerous fine cracks, called hair-checks. Overworking or delay in finishing until the hardening process has partially taken place should also be avoided because it results in unsatisfactory surfaces.

The finish will depend on the type of job being done. A gritty nonslippery "sidewalk" finish is desired for sidewalks, dairy barn floors and similar work. A coarse, scored surface is desired for driveways, feeding floors and paved lots. A smooth, troweled finish is desired for porches, basement floors, mangers and milk house floors.

A wood float is useful in making an even, gritty surface. A stiff coarse broom is useful in giving the surface a scored finish. The broom is run crosswise to the slab. A belt of wood, canvas or rubber is also often used in making a strongly scored surface. The belt should not be less than 6 nor more than 12 in. wide, and at least 2 ft. longer than the width of slab being finished. This is laid on the surface immediately after the wood float has been used.

For the first application, vigorous strokes crosswise of the slab and 12 in. long are used, advancing slowly forward along the slab as the surface is made smooth and even. The second application of the belt is made immediately after the water sheen disappears. Four-inch strokes are used and the movement forward along the slab is faster than the first application.

Smooth finishes are produced with a steel trowel. It

A scored finish produced by a stiff, coarse broom.

Steel trowel is used sparingly to give concrete smooth surface.

A wood float fills up the hollows and compacts the concrete.

is extremely important that too early or excessive troweling be avoided because it is likely to result in surfaces that will dust or develop numerous fine cracks. The trowel is not suitable for truing a surface. Any unevenness or irregularities in the surface of concrete that is to be troweled should be smoothed and leveled with a wood float. The steel trowel should be used sparingly and for only the final operation.

Curing

The next step in making watertight, durable, strong concrete is to provide proper curing conditions. As previously explained, concrete hardens because of a chemical reaction between portland cement and water. This process continues as long as temperatures are favorable and moisture is present to hydrate the cement.

The desirable properties of concrete—watertightness, durability and strength—under favorable curing conditions increase with age. The increase in strength is very rapid soon after the concrete is placed and continues slowly for an indefinite period. Tests made at various ages up to 5 years on concrete cured in moist atmosphere show that the increase in strength from 7 to 28 days is about equal to the increase from 6 months to 2 years. This is why it is so necessary to provide favorable curing conditions for the first month after the concrete is placed.

Concrete which is kept moist for 7 days is about 50 per cent stronger than that which is kept in dry air the entire period. If kept damp for one month the strength is about double that kept in dry air.

Tests also show that heat increases the rate of hardening. Concrete cured at 70 deg. generally hardens more than twice as quickly as concrete cured at a temperature slightly above freezing. All the desirable properties of concrete are improved by proper curing.

Thorough moist-curing aids in producing watertight concrete. As the cement paste in concrete hardens, additional solid matter is formed that closes off the spaces between the cement particles through which water might otherwise seep. The more complete the hydration or the hardening process, the denser and more watertight becomes the cement paste.

Increased resistance to wear is another result of proper curing; for this reason it is important to cure floors, pavements and other surfaces subject to wear. Continuous damp-curing, particularly in the early stages of hardening, aids in securing a hard, dense surface and in preventing checking and dusting.

Long wood float removes marks left by short float and gives concrete a gritty nonskid surface.

Form should be left on walls or other vertical surfaces for several days to prevent concrete from drying out too rapidly.

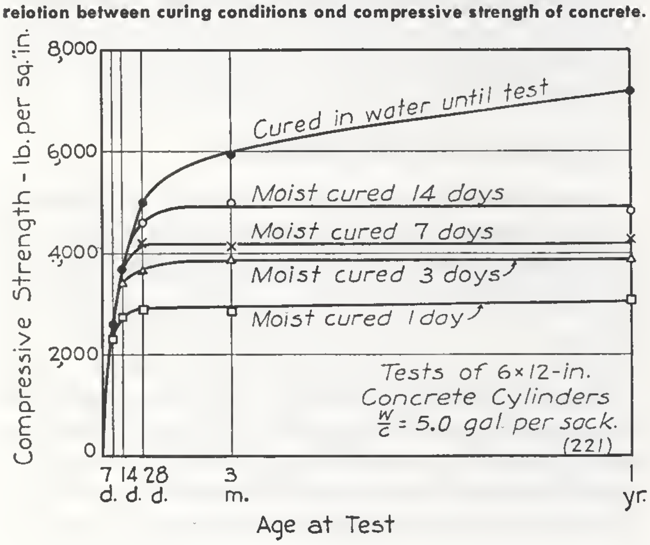
Wet sand on the floor and wetted burlap bags on the concrete posts help keep the concrete moist and aid in curing.

Wet burlap, canvas, sand or straw coverings are often used to protect newly placed concrete. The covering is placed as soon as it can be done without marring the surface. Care should be taken to keep the covering continuously wet by sprinkling. When a cover is not used, wetting of the concrete should be begun as soon as possible after finishing and the surface should not be permitted to dry during the curing period. Floors, sidewalks, pavements and other flat surfaces require careful attention as moisture is lost very rapidly by evaporation because of the relatively large exposed surface. Ponding is a good method of curing for flat surfaces. With this method, the surface to be cured is surrounded by small earth dikes and then kept flooded with water for several days.

Walls and other vertical surfaces can be protected by leaving the forms in place temporarily or by hanging canvas or burlap over them. Such coverings are kept constantly moist by sprinkling. Curing should continue for at least 7 days, and for longer periods when it is practical to do so.

Protecting concrete in cold weather to prevent freezing and to insure proper curing is discussed under "Cold Weather Construction", page 39.

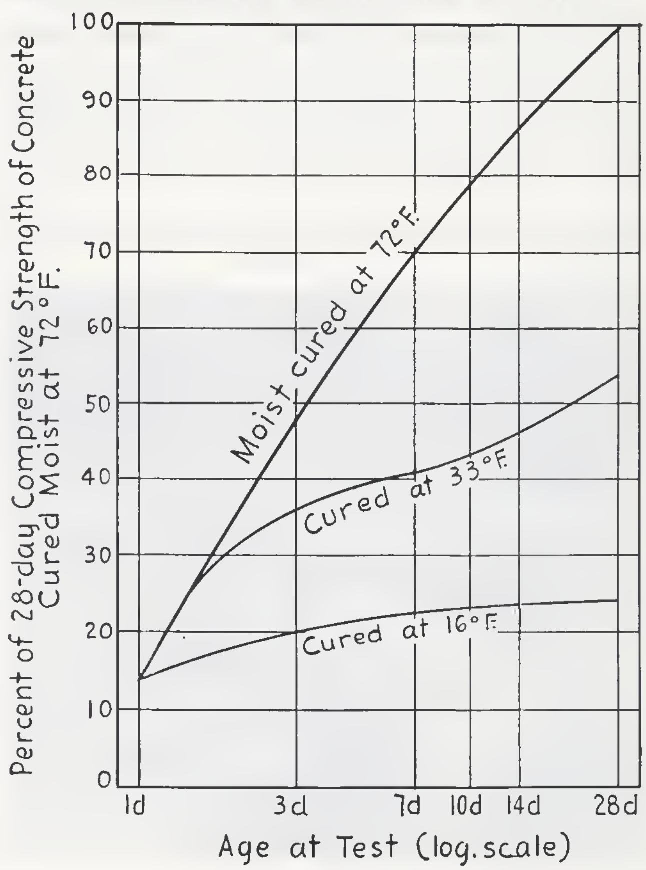
Concrete hardens best in the presence of moisture. This diagram shows relation between curing conditions and compressive strength of concrete.



Questions

1. Can good concrete be made by hand-mixing?
2. When is the batch thoroughly mixed?
3. For how long should the batch be mixed in a machine mixer?
4. Is the time of mixing of any importance?
5. What precautions should be observed when placing concrete?
6. What effect does spading concrete have?
7. What is meant by finishing concrete?
8. What are some ways concrete may be finished?
9. What is the effect of temperature on the rate of hardening of concrete?
10. Estimate quantity of materials for a sidewalk 3 ft. wide, 4 in. thick and 100 ft. long, 1: 2½: 3½ mixture.
11. Estimate quantity of materials for foundation for a poultry house 30x30 ft., 6-in. wall, average 4 ft. high, 1: 3: 4 mixture.
12. What is meant by curing of concrete and what conditions are necessary for proper curing?
13. How can uniform concrete be obtained?
14. How can segregation be prevented?
15. Compare the probable 28-day strength of a mixture made with 7 gal. of water to the sack of cement and one made with only 6 gal.

Effect of curing temperature on compressive strength of concrete.



CHAPTER 5

FORMS AND FORM MAKING

Concrete, being plastic at the time of mixing, can be made to conform to almost any desired sbape. The degree of success with whicb this may be accomplished depends very largely upon tbe forms used. Forms are tbe molds or receptacles in which tbe concrete is placed so that it will bave tbe desired sbape wben hardened.

Form Requirements

Correctness of shape and size is the first requirement of forms for concrete. This may at times seem difficult to attain because the form must be made just the reverse of tbe object to be cast. Finisbed concrete will have no smoother surface than the forms.

Forms must be substantial enough to retain their sbape wbcn filled with wet concrete, wbich is fluid and heavy, and exerts great pressure on the forms. It is not sufficient tbat they be strong; they must also be rigid. Disappointment will result if one finds after concrete is placed that the forms are deformed by resulting pressures.

The forms must be tight. The escape of the water-cement paste from small openings will change the character of the remaining mixture. Forms should be easily filled and easily removed after the concrete has bardened. Double-beaded nails or screws whicb can be witbdrawn readily will assist greatly in removing forms without damaging the new concrete. Forms should be rigid enough to permit spading of the concrete.

Forms made of panels simplify farm work. Such panels can be used over and over again.

Forms must be securely tied and strongly braced to retain their shape when filled.

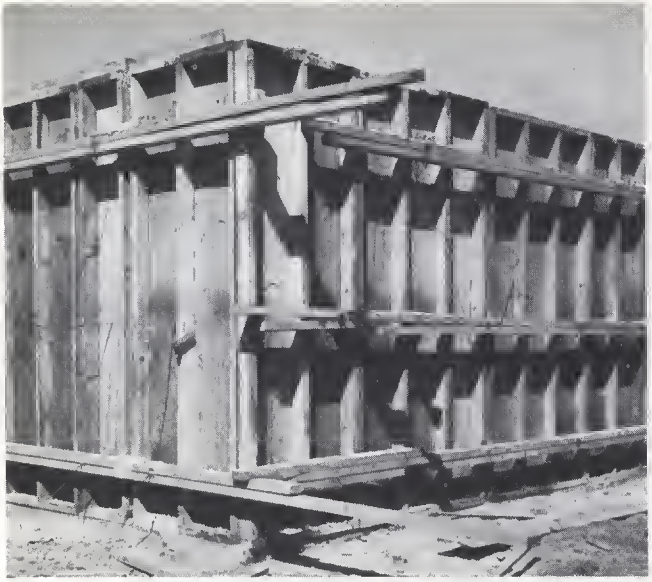
Forms sbould be reasonable in cost, particularly when used only once. Greater care or expense in making forms may be justified when the work is elaborate or the forms are to be used a number of times.

Materials and Construction

Several materials are suitable for the construction of concrete forms. Individual requirements will be tbe determining factors. Only a few general considerations can be listed bere.

Wood

Any good, sound lumber, free from loose knots and decay, is suitable for form work. Tbe use of sheathing lumber dressed on one side and botb edges is recommended because forms built of it are easy to remove. Where smootb true surfaces are required it is best to



Panel forms are made rigid with metal ties and strong braces.

use lumber that is dressed on all four sides. Tight joints are obtained by using tongue-and-groove stock or ship-lap. To prevent waste, lumber is bought in the commercial length nearest to the height or length of the forms.

The sizes of lumber commonly used in form work are: 1-in. stock for floor, foundation and wall forms, columns and beam sides; 2-in. for beam bottoms and heavy concrete construction; 2x4-in. for form studs, column yokes and framing for panels; 2x6 or 2x8-in. for stringers and joists; 3x4 or 4x4-in. for posts, struts, shores, uprights and sometimes for stringers; 1-or 2-in. for cleats; and 1x6-in. for crossties and similar bracing.

Forms may be built in sections or panels so constructed that they can be removed easily and used again, or so that the lumber in them can be used in other work.

Forms often can be assembled in part by clamps and wedges with only a few nails partly driven. Metal pans, adjustable shores and wire ties are other accessories commonly used. A steel wrecking or stripping bar is a useful tool for stripping wood forms from the finished concrete.

Plywood

A grade of plywood has been developed which is suitable for concrete forms. A special bonding agent, surface oiling and edge sealing combine to make it a material which can be re-used many times. Large smooth panels minimize the number of joints and tend to simplify construction. This material is strong and rigid and hence requires fewer supports. It is identified by a special grade mark and is available in sizes up to 4x8 ft. and in thicknesses ranging from ½ in. to ¾ in. It makes a smooth surface on the concrete and can be bent to form curved surfaces. Further advantages are that it can be sawed easily and nailed close to the edge without previous drilling and without splitting.

Metals

Steel, cast iron and other metals make excellent forms for concrete and are used extensively where forms can be used many times. These may be such units as wall panels which can be assembled in a variety of shapes or in special forms for units such as blocks, ornamental vases, etc. As such forms are practically indestructible, the cost per unit cast may become quite small as the number increases.

Synthetic Materials

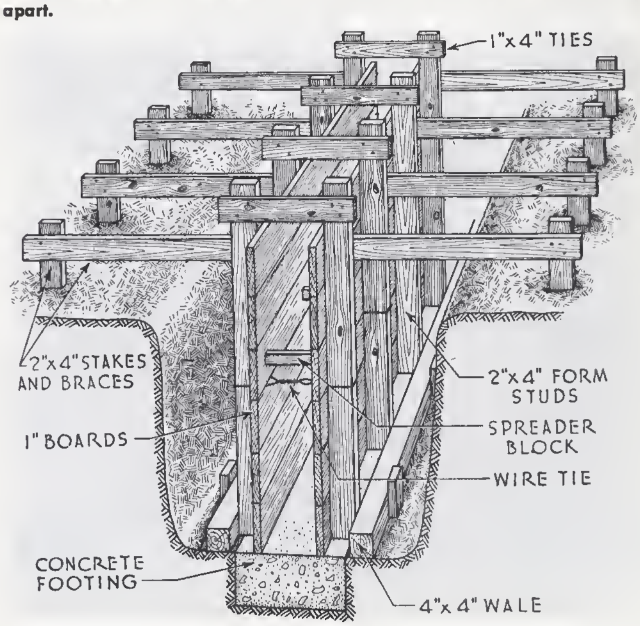
Certain hard boards made from cellulose fibers are now available. These are hard and smooth and may be obtained in larger pieces than lumber. With proper workability and manipulation of the concrete they impart a smooth surface; with such forms it is possible to secure an area as large as 4x12 ft. or more, unbroken by lines from splices or cracks. Some of these materials, impregnated with oil at the factory, may be used often.

Such forms must be supported carefully or used inside wood forms. Without such support, the bulging from pressure of the concrete often is objectionable.

Earth

For foundation work below ground level, forms will not be necessary if the earth is so firm that the sides of the excavation will stand without caving. When placing and tamping the concrete, however, care must be taken not to knock down the earth into the concrete, as this will cause weak and porous spots in the wall.

Wood spacers and wire ties hold foundation forms the correct distance apart.



Earth cores are often convenient for forming the inside of watering troughs, bird baths, etc.

Plaster, Glue and Special Molds

In ornamental work, where the making of complex shapes is necessary, glue, plaster and special molds are employed. Considerable skill is required in their preparation and use. With either of these materials it is possible to duplicate intricate designs. With glue one can make forms for casting objects which are undercut in character, that is, so formed that it would be impossible to remove a rigid form. The glue remains sufficiently plastic to bend when removing, but is rigid enough to hold its shape when concrete is being placed. Special instruction or reference to a text is desirable before working with plaster or glue.

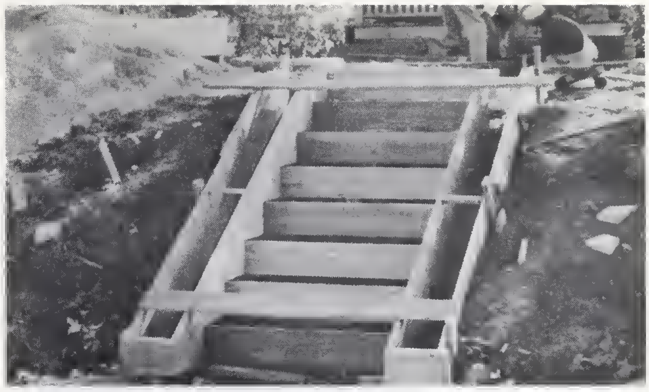
Care and Use of Forms

To prevent adhesion of concrete and to make form removal easy, it is customary to oil form faces which come in contact with concrete. A light, clear lubricating oil which can be purchased from filling stations is suitable for this purpose. The oil should be cut with an equal amount of kerosene for easy brushing. Paraffin oil diluted with kerosene or benzine is recommended where concrete is to be painted or stuccoed. Forms are cleaned and again oiled each time before re-use. Dry, untreated wood forms will absorb an appreciable quantity of water from the concrete, often leaving the surface too dry for best results.

Lubricating oil should not be applied to form surfaces that contact concrete to be painted or stuccoed.

Where construction requires the installation of conduits, pipes and other service leads, these should be put in position before concrete is placed.

The surface of panel is well oiled to prevent sticking.



Careful building of forms is important in obtaining a satisfactory concrete job.

After forms are made they should be well braced in position to prevent bulging of the wet concrete while it is being tamped into place. Wood spacers should be used for walls to hold opposite form faces the correct distance apart. Wire ties, passed through or around form studs and across the space between forms, tighten the forms against the spacers and hold them in true alignment so that the finished wall will be straight and even in thickness.

Wire ties are tightened by twisting. Spacers must be removed as concreting progresses; otherwise a permanent blemish in the wall will result.

For exposed work, best results are obtained by using spreader ties which may be twisted or broken off about 1 in. back of the surface. Holes are patched by forcing in a grout of the same proportions as the mortar used in the concrete. To prevent patched areas from appearing darker than the wall, from ¼ to ½ the cement used in patching should be white portland cement.

In summer weather, wall forms generally can be stripped after 1 or 2 days and in colder weather from 4 to 7 days. Forms for concrete floors, roofs and other similar construction are left in place at least 7 days in summer and 14 days in cold weather. Forms must never be removed until it is certain that the concrete has hardened sufficiently to be self-sustaining.

Questions

1. What are forms?
2. Is form building important? Why?
3. How are forms treated to prevent the concrete's sticking and to make their removal easy?
4. What precautions are taken when building forms so that they will keep in line and in shape when subjected to the great weight of concrete?
5. When can the forms be removed from concrete?
6. Name five characteristics of good forms.
7. What are wire ties and their purpose in forms?
8. How would untreated dry lumber forms affect the quality of the concrete?

CHAPTER 6

SPECIAL PROCESSES AND PRECAUTIONS

It is often necessary to utilize certain special processes or to observe special precautions in making concrete which is intended to satisfy some specific requirement other than strength and durability or which must be placed under special conditions. Such cases include:

- Watertight construction.
- Cold weather placing.
- Cyclopean concrete.
- Lightweight concrete.
- Shotcrete.

Watertight Construction

Watertight construction results when the concrete itself is made watertight and when workmanship is such that all seams and other construction joints will resist the passage of water. Leakage through concrete walls often is due to openings in construction joints rather than to the lack of watertightness in the concrete itself. How to make watertight seams is discussed under "Placing", pages 32 and 33.

One of the main reasons for making concrete watertight is that moisture entering concrete may result in structural defects. For example, the water may freeze and break the bond between the cement paste and aggregates, thus lowering the quality of the concrete. Watertightness adds to strength and durability.

Durable aggregates completely coated with a cement paste that resists the passage of water are necessary for watertight concrete. Leakage through concrete, if any, usually is through the paste and can be prevented by having a sufficient quantity of watertight paste to coat all particles of aggregate and to fill all spaces between them. To produce a watertight paste, use not more than 6 gal. of water for each sack of cement, allowing for moisture in the aggregates.

To be sure that concrete will be watertight, it is necessary to have a plastic, workable mixture that can be thoroughly spaded to fill the forms without segregation of the materials. Thorough mixing, therefore, is required. This produces uniform batches, completely coats the aggregates with cement paste and makes the concrete more plastic, all of which make placing easier.

Use methods of handling that will permit the concrete to be transported and placed without segregation of the materials. Continue placing without stopping if possible. Where interruption cannot be avoided, special precautions should be taken to obtain good bond with the hardened concrete. (See discussion of "Placing", pages 32 and 33.)

Favorable curing conditions are essential. One of the most important steps in making concrete that is dense and watertight is to keep concrete moist and at proper temperatures, beginning soon after it is placed.

Cold Weather Construction

Concrete can be made during cold weather just as well as at any other time, if certain precautions are taken to insure proper curing.

In early winter when freezing temperatures occur only at night it is necessary to protect concrete from freezing after it is placed. When freezing temperatures prevail both day and night, it is necessary to heat the mixing water and aggregates as well as to protect the concrete.

Heating Water

Water is commonly heated in a large kettle, oil drum, tank or similar container supported over a fire. It can also be heated by discharging live steam into it. Regardless of the method of heating, it is best to take care that the temperature of the water is never greater than 150 deg. F. when it comes in contact with the cement

When concrete work is done in cold weather, water and other ingredients are heated so that concrete will have a temperature of 70 deg. or more when placed in the forms.

Aggregate is heated by piling over metal culvert pipe or barrel laid on side in which fire is built.

in the mixture; otherwise a too quick or flash set may take place. However, boiling water may be added to the aggregates before the cement is included. When this is done, the aggregates cool the water so that danger of a flash set is eliminated.

Heating Aggregates

Several methods of heating sand and other aggregates are commonly used. The materials may be banked over a metal barrel laid on its side, a section of smokestack or some other improvised heater, and a fire kindled inside. A satisfactory heater for small jobs can be made by building a firebox of concrete masonry units with a sheet-iron cover on which the aggregates are piled.

Sand and coarse aggregate should be heated separately to prevent them from becoming mixed. Frequent turning will result in uniform heating and thaw out all frost and ice. When steam is available, sand can be heated by placing a perforated 1-in. pipe into the pile and blowing steam through it. A tarpaulin cover over the sand will reduce the loss of heat. Cement should not be heated.

The temperature of aggregates when placed in the mixer should not exceed 140 deg. F.

Mixing and Placing Concrete

Make the concrete as stiff as possible and yet obtain a mix that can be readily placed and finished. Place immediately after mixing to prevent loss of heat. Remove frost, snow or ice from the forms before the concrete is placed.

If the ground on which concrete is to be placed is frozen, it should be thawed out before the concrete is placed. If possible, have excavating done before the ground is frozen, covering the excavated areas with straw or other suitable coverings to protect the earth from freezing.

Heat hastens the hardening of concrete; cold retards it. When concrete is placed in the forms it is best that it have a temperature of not less than 60 deg. nor more than 80 deg. F. In cold weather the concrete should be maintained at a temperature of 50 deg. or higher for at least 5 days after placing.

Use of Admixtures

Specifications usually prohibit the use of salts, chemicals or other foreign materials in the mix to lower the freezing point of the concrete. Admixtures intended to quicken the hardening of the concrete are permitted only when used in quantities which will not be injurious.

Tests made on concrete jobs and in laboratories show that within certain limits* small amounts of calcium chloride may be used in portland cement mixtures to hasten hardening. The best results are obtained with 2 to 4 per cent of calcium chloride by weight of the cement. If greater amounts are used, loss of strength results.

These compounds should never be used as a substitute for heating water and aggregates and furnishing proper protection and heat to the new concrete, but only as a means of increasing the rate of hardening.

The calcium chloride crystals are dissolved in the mixing water before adding it to other materials in the mixer. Most contractors make up a solution of known concentration, adding the desired amount to each batch. Thus, to use 2 lb. of calcium chloride per sack of cement, a solution containing 1 lb. per quart can be made, 2 qt. of the solution being added to the mixture for each sack of cement in the batch. It is important to remember that this solution is to be regarded as part of the mixing water.

Protecting Concrete

As soon as the concrete is placed it is protected to retain heat. Concrete walks, floors, pavements and other horizontal surfaces can be protected by covering with heavy paper and then with hay or straw 10 to 12 in. deep.

Outside walls can be protected by coverings of canvas or straw or by building enclosures around them and heating the interior with oil or coke stoves (the latter are commonly known as salamanders), or some other form of stove which will provide considerable heat without smoke. Salamanders and other stoves should

*There is evidence to show that calcium chloride and similar compounds do not react in the same manner with all brands of portland cement. Trial batches of the brand of cement and the brand of accelerator proposed should be made up and the rate of hardening at the specified temperature noted before proceeding with their use in important work.

not be placed near enough to fresh concrete to cause it to dry out. To keep the concrete moist is especially important while heat is being applied, since winter air when heated has a severe drying effect.

Removing Forms

Too early removal of forms is to be guarded against when concreting in cold weather. It is recommended that forms remain in place until the concrete has attained sufficient strength to sustain its own weight in addition to any other load that may be placed upon it during construction.

Frozen concrete is frequently mistaken for properly hardened concrete because it may have the same "ring" when struck with a hammer. A reliable test is to apply heat or hot water to the surface. If frozen, the concrete will soften on thawing.

Cyclopean Concrete

When large field stones or cobblestones are imbedded in concrete for massive structures, such as foundations, dams, piers and retaining walls, the product is called cyclopean concrete. The practicability of its use depends largely on the labor involved. Under farm conditions, where labor is available and the disposal of the rock and boulders is a problem, it often effects a considerable saving. The stones must be sound and clean and each one completely surrounded by concrete. The large stones should not lie near each other nor near an exposed surface.

Shotcrete

Within recent years there has been developed a method by means of which mortar can be applied with a gun. This product is called shotcrete and consists of sand and cement of various proportions, mixed dry, placed in the cement-gun dry, and ejected through a rubber hose by pneumatic pressure. Water is added at the nozzle. The force of impact expels superfluous moisture and air, and part of the sand (referred to as rebound), thus solidifying the mass and, if properly applied, producing a mass of great density and strength.

Concrete is protected against freezing by covering with waterproof building paper and then with hay or straw.

This product lends itself to placing of concrete in difficult locations and in plastering and repair work.

Lightweight Concrete

By using aggregates of light weight, the weight of concrete may be reduced considerably. Lightweight concrete is desirable for roof slabs, partitions, floor fills, fireproofing, masonry units and other purposes. Where lightweight materials are to be used in concrete which will carry a load, tests should be made to determine the combination of materials necessary to produce the required strength.

Patented methods of aerating concrete are in use to some extent. For this process finely divided chemicals which generate gases are added to cement paste or mortar, causing it to expand so that upon hardening it is full of air spaces.

Concrete having weight as low as 50 lb. per cubic foot may be made by aerating. Concrete having weight as low as 25 lb. per cubic foot may be made with lightweight aggregate. Ordinary concrete weighs about 150 lb. per cubic foot.

Lightweight concrete has a lower heat conductivity and hence better insulating value than concrete made of heavy aggregates. Aggregates for lightweight concrete are made of a wide variety of materials. Availability in a given location may be the determining factor in selection of aggregate to use. Brief descriptions of several aggregates are given in the following paragraphs.

Cinders

Cinders from anthracite and bituminous coal differ somewhat in physical characteristics, but they are both suitable for concrete when meeting certain requirements. They should be obtained from sources where a large quantity of coal is burned. Usually industrial plants, gas works and locomotives use coal of uniform quality and have efficient burners which produce uniform cinders. Cinders from small domestic furnaces generally are not suitable for concrete. Cinders should be well graded from coarse to fine.

Burned Clay or Shale

A cellular, inert burned clay or shale material may be used in fine and coarse sizes in concrete or as the coarse aggregate only, combining with ordinary sand as the fine aggregate. It can be made from a great variety of clays and shales and is frequently made in brick plants.

Expanded Slag

Blast furnace slag has been used for more than 40 years as aggregate in concrete for all kinds of structures.

Both laboratory results and investigations of structures in service have demonstrated the excellent performance of air-cooled blast furnace slag aggregate. It is used chiefly for coarse aggregate since it is not generally economical commercially to crush slag for use as fine aggregate. Well-graded sand should be used in combination with coarse slag and proportions adjusted until the proper workability is obtained.

Pumice

Pumice, pumicite and tuff are siliceous minerals of volcanic origin similar chemically but differing in physical properties. Pumice is light in weight and when used as aggregate yields a concrete which serves as a good insulator and accoustical plaster. Its use in the United States is limited primarily to the West.

Diatomite

Diatomite is essentially composed of deposits of the siliceous shells of microscopic aquatic plants called diatoms. Large deposits are found in the western states and on the eastern seaboard.

Perlite

Perlite is a natural volcanic glass which may appear solid but is actually permeated with tiny pockets of gas. When exposed to a live flame, these pockets are greatly expanded.

Vermiculite

This material is formed when certain micas are dried, ground and subjected to about 1,800 deg. of heat for from 4 to 8 seconds. It is obtained primarily in Montana and Colorado. Its principal use in concrete is for heat and sound insulation.

The following table, taken from *Lightweight Aggregates for Concrete*, published by the Office of the Housing Expediter, Washington, D.C., shows the weight of lightweight aggregates and of concrete obtained by using them.

Type of aggregate	Wt. of aggregate per cu.ft. (lb.)	Wt. per cu.ft. of concrete using aggregate (lb.)
Burned clay or shale . .	40-60	100-120
Expanded slag . . .	40-60	90-100
Cinders	40-50 (plus sand)	110-115
Pumice	30-60	60-90
Diatomite	28-40	55-70
Perlite	6-16	40-65
Vermiculite	6-10	25-50

Sawdust Concrete

Several state agricultural colleges have studied the characteristics of sawdust concrete, as this material has been used to a limited extent in constructing floors in farm buildings. Information given here is based entirely on these studies.

In general, sawdust in concrete seriously reduces its strength and durability. Experiments at the University of Minnesota have shown that sawdust concrete has only 10 to 20 per cent of the strength of normal sand and gravel concrete. Sawdust concrete is therefore principally an insulating material and should never be used where high strength and durability are required. It should not be used where it will be subjected to heavy wheel traffic or other severe abrasive action. While this material may be satisfactory as a floor topping in pens for livestock and for cow stall platforms, it should not be used in main alleys, gutters or other places where it will receive hard usage or where a good deal of moisture may be present. It is also doubtful that this material should be used for flooring poultry yards, feed lots, barnyards or other construction where it would be exposed to freezing and thawing and other severe weathering action.

Limited farm use of sawdust concrete has been in floor and other construction where strength is not important but where it is desired to provide a construction material of a fairly good insulating value.

The following conclusions can be drawn from the experimental work with sawdust concrete at various state universities, principally those of Minnesota, Wisconsin and New Hampshire:

—Sawdust concrete mixtures are of rather uncertain and unpredictable strength. The only safe procedure is to test trial mixes to see whether desired hardness can be produced.

—Mix proportions are preferably about 1: 3 or 1:3½ or 1:4. Richer mixes are stronger but heavier; they are also poor insulators. Leaner mixes are of extremely low strength and will burn.

—Amount of water and method of adding it to the mix greatly affect strength of sawdust concrete. Previous soaking of the sawdust for 24 hours or longer increases the strength.

—Sawdust used should pass through ¼-in. screen and should preferably be spruce or Norway pine. Commercial sawdust and sawdust from jack pine, aspen and ponderosa pine have given fair results.

Questions

1. What factors must be considered in securing a watertight concrete?
2. How does the water-cement ratio affect the watertightness of the cement paste?
3. Why is the complete incorporation of the aggregates in the cement paste essential to watertightness?
4. What effect does heating the ingredients have upon the rate of hardening?
5. How can lightweight concrete be secured?

CHAPTER 7

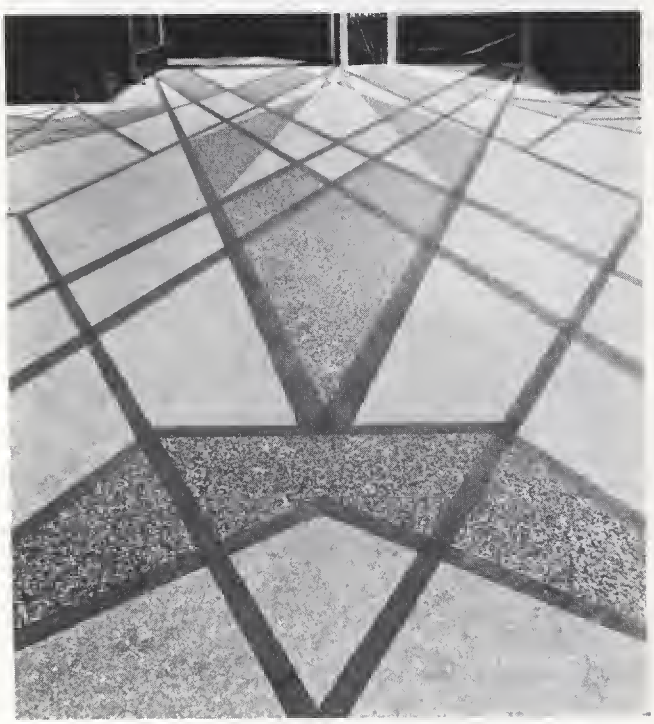
COLORED CONCRETE, SPECIAL SURFACE FINISHES, PAINTING AND STUCCO

Concrete is a construction material which lends itself to a variety of finishes and treatments limited only by the ingenuity of the craftsman. Concrete can be made in a wide choice of colors. It can be given special surface treatments. Concrete in its plastic state takes the lines, marking and patterns imparted to it by the shape and surface characteristics of the forms in which it is molded. Other surface treatments include application of stains, portland cement base paints and portland cement stucco. The subject of colored concrete and special finishes is so broad that it is possible to present only some of the more general features in this manual.

Colored Concrete

Colored concrete can be obtained by using pigment in the cement paste, by dusting the top of the fresh concrete with pigments and cement, and by applying acid stains. (Use of selected aggregates in making colored concrete is treated under "Special Surface Finishes", page 47.)

A colored concrete sidewalk laid in modernistic pattern.



Coloring Pigments

A coloring pigment suitable for use in concrete must fulfill the following requirements: (1) It must be durable under exposure to sunlight and weather; (2) It must produce intense color; (3) It must be of such composition that it will not react chemically with the cement to the detriment of either cement or color.

These requirements are best fulfilled with mineral oxide pigments. Other pigments, such as organic dyes, have a tendency to fade and may reduce the strength of concrete. There are two satisfactory kinds of mineral oxides available: (1) Natural oxides that come direct from the mines, and (2) Manufactured pigments which are prepared especially for concrete work.

Ordinarily, natural mineral pigments cost less per pound than manufactured pigments and may be used where dull colors are satisfactory. Where bright colors are desired, manufactured pigments produce best results. To obtain a given intensity of color, more of the natural pigment is required than of manufactured pigment. It frequently happens that a smaller amount of higher-priced, manufactured pigment actually produces the desired results at a lower cost than the cheaper natural pigment.

A general guide for the selection of coloring materials follows:

For white, use white portland cement.

For brown, use burnt umber or brown oxide of iron. Yellow oxide of iron may be added to obtain modification of this color.

For buff, use yellow ocher or yellow oxide of iron. Red oxide of iron may be added in limited quantities.

For grey, use small quantities of black iron oxide, manganese black or Germantown lampblack.

For green, use chromium oxide. Yellow oxide of iron may be added.

For pink, use small quantity of red oxide of iron.

Colored concrete tile floor.

For rose, use red oxide of iron.

For cream, use yellow oxide of iron in small quantities.

The color produced in concrete is determined primarily by the proportion of pigment to cement and not by the proportion of pigment to cubic feet of mortar or concrete. Because of this, modern color specifications give the weight of coloring pigment to be used per sack of cement for cement paste and per square foot for dust-on method.

It has been found that pigments safely may be used in amounts up to 10 per cent of the weight of the cement in cement paste—that is, 9 lb. of coloring pigment per sack (94 lb.) of cement. This limit may be exceeded with some pigments and under certain conditions. In such cases manufacturers' directions should be followed.

With high-grade pigments, the amount recommended as a maximum—10 per cent of the weight of the cement—will usually produce deep shades of color. Lighter shades are obtained by using less pigment, and variations of colors or shades are obtained by mixing two or more pigments.

The full coloring value of pigments can be obtained only with white portland cement. White cement must be used to obtain the more delicate shades of the lighter colors and for white finishes. When clear white is desired, white sand and cement should be used. The use of white portland cement with yellow and brown sands will produce varying shades of cream, yellow and buff. If the colors desired can be secured without pigments such practice is to be recommended.

The aggregates used in colored concrete should be as near the color of the mortar as possible. If such aggregates are not available, light-colored semitransparent aggregates will give best results.

Variation in the composition of concrete materials as well as in the coloring pigments makes color formulas only approximate. For this reason it is suggested that after selecting the primary color desired, the exact shade be determined by preparing a number of small mortar panels with the same materials and proportions as are intended for the finished job. The sample mortar panels should be 6 or 8 in. by 12 in. and about 1 in. thick. The proportions used for the different panels are carefully recorded so that when the correct shade is determined the exact proportion for that shade can be used on the job. Samples are stored away for 4 or 5 days under curing conditions the same as those on the job. After they are cured they are dried and wiped off with a rag dipped in equal parts of paraffin oil and benzine to bring out the color, and then inspected.

Mineral pigments vary considerably in coloring values. Most architects and builders depend upon the reputation of the manufacturer of pigments for assurance that the quality of the material is satisfactory for concrete work. In general, the finer a pigment is ground the greater is its coloring ability and the less the amount required.

Mixing Colored Concrete

In producing high-quality colored concrete, the pigment and cement are mixed together before they are delivered on the job. Thorough mixing, which is hard to accomplish on the job, is essential for uniform color in the finished work. Coloring pigments do not penetrate the particles of cement, as do dyes in coloring cloth, but form a coating around the particles.

Where factory-prepared colored portland cement is available, it is often economical to use.

Another method of blending mineral oxide pigments with portland cement, especially suitable for small jobs, is to sift the pigment and cement through a fine screen until thoroughly mixed. The correct quantities of pigment and cement for a 1-sack batch are first measured out separately. The cement and pigment are then mixed thoroughly, the materials passing through the screen as many times as necessary to obtain uniform color.

It is sometimes necessary to use a concrete mixer for mixing pigment and cement. In this case the mixer must be dry and free from loose particles of hardened concrete or mortar.

It is necessary to measure all materials accurately, particularly where the work requires several batches. Even a slight variation in the amounts of any of the materials, particularly the pigment and water, is likely

Floor topping mix of proper consistency. Five gallons of water per sack of cement was used.

to cause noticeable variation in color.

For almost all colored concrete work, a mixture containing not more than 5 gal. of water per sack of cement is recommended when aggregates are dry. The mixture of colored concrete is made as stiff as possible without the sacrifice of workability. It should require light tamping or rolling to settle it into place. In determining the correct consistency for colored concrete, the slump test described on page 25 will be useful. It also will be helpful in maintaining uniform consistency in all batches. Colored concrete toppings should have a slump of not more than 2 to 4 in.

The recommended trial proportion for colored concrete is 1 sack of cement, 1 cu.ft. of sand and 1¾ cu. ft. of clean, hard pea gravel or crushed stone or slag ranging from ⅛ to ¼ in. in size and containing no soft, flat or elongated particles. Not more than 3 per cent of the fine aggregate should pass the 100-mesh screen and not more than 15 per cent should pass the 50-mesh screen.

When materials are mixed on the job, the colored cement is mixed with the sand or other fine aggregate to be used in the concrete. With a 1:1:1¾ trial mix, for example, 1 sack of colored cement and 1 cu.ft. of sand are first thoroughly mixed dry. Then 1¾ cu.ft. of coarse aggregate is added and the materials thoroughly mixed again until uniform color is obtained; this is done before water is added. Thorough mixing after water is added also is essential.

Placing Colored Concrete

Colored concrete may be placed by any one of three methods: two-course integral, regular two-course or the one-course method.

Two-Course Integral Method. This method, in which the colored topping is placed before the base course hardens, is used when the colored concrete can be placed and finished immediately, as in driveways, tennis courts, walks and pavements. The concrete for the base is mixed and placed as in ordinary work.

Concrete topping should not be applied until the base course has stiffened somewhat and all excess water has evaporated or has been removed with a broom, belt, float or other means. Brooming, for example, removes water, scum and laitance and produces a rough surface providing a good bond for the colored topping.

Regular Two-Course Method. This method is best suited to floor work and similar construction where it is not desirable to place the topping until other construction work has been completed. When this method is to be used, it is best to leave the surface of the base course fairly rough to secure a good bond with the topping. Before placing the topping, this surface is thoroughly cleaned and dampened. A thin coat of cement grout is broomed onto the surface a short distance ahead of the topping as the latter is placed. In either the two-course integral or regular two-course method, placing the topping is essentially the same. The minimum thickness of the topping is usually 1 in. As soon as the topping is placed it is leveled off with a strikeboard and given a wood-float finish.

One-Course Method. Where the full thickness of concrete is placed, as in the one-course method, placing is much the same as in ordinary work. However, it is seldom economical to place the full thickness with colored concrete except for thin slabs or for work to be given only tints rather than deep colors.

Finishing Colored Concrete

Where a smoother finish than that imparted by the wood float is desired, the surface is left undisturbed for 30 to 45 minutes, depending upon temperature and

Placing the base for two-course integral color work.

weather conditions. When all surface water has disappeared and there is no visible sheen, the concrete is finished lightly with a steel trowel. It is important to trowel only in one direction to get uniform color.

Too much emphasis cannot be placed on the necessity for extreme care in the use of the steel trowel. An expert can develop with a minimum amount of steel troweling a beautiful, smooth surface which will be free from dusting or checking and which will have good wearing quality. On the other hand, excessive troweling draws fine material to the surface which greatly reduces its wearing quality. A good point to keep in mind is that the fewer strokes required to produce a smooth surface, the better will be the job. Additional information on finishing is given on page 33.

Dust-On Colored Topping

The method of making colored concrete given in the preceding paragraphs applies to the color pigment being incorporated in the topping mix. The dust-on method of coloring is often used on floors and other flat surfaces not subject to heavy wear. This method results in a bright color and is economical in the use of pigment.

The dust-on method of coloring concrete is as follows: After the topping of plain (uncolored) concrete has been screeded level and all surface water removed, the dust-on mixture is distributed uniformly over the surface, applying it at the rate of not less than 1¼ lb. to the square foot. The dust-on mixture is floated and worked into the topping. Floating is discontinued when surface becomes wet. After the water sheen produced by floating has practically disappeared, the surface is troweled to a smooth finish of uniform color.

Dust-on mixture usually consists of 1 part of portland cement, 1 to 1½ parts of well-graded sand, at least 80 per cent of which passes a No. 30 sieve, and the amount of pigment required to produce a finish of the desired color. It is essential that all materials be accurately proportioned and that all batches be exactly alike. Portland cement, sand and pigment are mixed together dry until the mixture is of uniform color. The amount of color required is best determined by making up sample slabs under job conditions and allowing them to cure and dry.

Ordinarily, from 10 to 15 lb. of pigment per sack of portland cement will be sufficient in preparing the dust-on mixture where dark pigments are used, and 15 to 20 lb. per sack for light pigments. When the mixture is floated into the topping the pigment becomes mixed with it and the recommended limit of pigment to cement is not exceeded.

Outdoor checkerboard made with colored concrete.

Curing

The proper curing of colored concrete is important, for it develops strength, watertightness and resistance to wear. The recommended methods of curing discussed on pages 34 and 35 should be followed.

Acid Stains

Inorganic acid stains when properly applied produce attractive colored surfaces. Various tones of brown, buff and green in single colors or combinations of several colors can be produced. The stain is a chemical compound which when applied to concrete surfaces results in the production of the colors. The chemical is applied to concrete after it hardens. The use of stains requires skill and the recommendations of the manufacturer should be followed closely to obtain best results.

Efflorescence

Efflorescence, sometimes called blooming, is a deposit on the surface and in the pores of masonry building materials such as brick, clay, tile, limestone, marble, terra cotta and concrete. This deposit, being whitish in color, is particularly noticeable and objectionable on colored concrete surfaces. It usually results from the passage of water out of the material carrying soluble substances dissolved from some constituent of the material. When this water reaches the surface and evaporates, the substances remain as a whitish deposit. Obviously, if concrete is made watertight, the likelihood of efflorescence is reduced to a minimum. Proper proportioning of the mixture, use of not more than 5 gal. of water per sack of cement, thorough mixing, and proper placing, finishing and curing will produce watertight colored concrete.

Should efflorescence occur, it may be dissolved by a dilute solution of muriatic acid (1 part of concentrated acid to 10 parts of water). In using this treatment the surface of the concrete is wet before the acid is applied and is thoroughly washed after the acid treatment.

The length of time required for the acid solution to dissolve efflorescence will depend upon the amount of the latter. In most cases, the acid can be washed off within three or four minutes. It is best not to leave

the acid solution on longer than four minutes, for it may etch the colored concrete. If some deposit remains after the first application, a second can be made. The acid solution should be brushed on smoothly, the least amount possible used for each application.

Efflorescence also can be removed with a solution of equal parts of paraffin oil and benzine rubbed vigorously into the surface when the concrete is dry. This treatment also improves the wearing qualities of the surface by filling the pores and bringing out the color more uniformly. It is frequently applied to concrete surfaces for these reasons only.

Cleaning Colored Concrete

Colored concrete surfaces may be cleaned and made more dense by washing with liquid soap. When this treatment is used the soap should be applied and allowed to stand overnight, and washed off thoroughly the next morning.

The application of ordinary floor wax once a month after the concrete is dry and clean will produce deep colors, improve the wearing surface and make it easy to keep clean. After the first two or three waxings, two applications a year will be sufficient unless the surface is to be subjected to unusually severe wear.

Special Surface Finishes

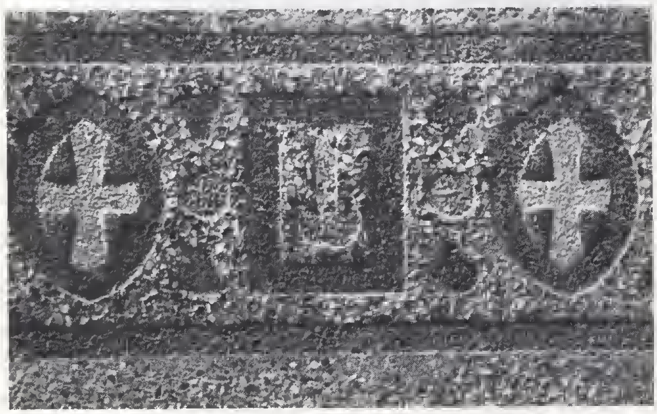
Special surface finishes can be obtained by use of selected aggregates, by using forms which impart markings or patterns or by special treatment after the concrete hardens.

Use of Selected Aggregates

Among the most attractive finishes are those which are pre-arranged when mixing the materials. Aggregates are selected for their color as well as for their ability to take polish. Among the aggregates commonly used are white sand, marble chips, granite screenings, crushed feldspar, mica-spar, crushed slag, garnet sand and similar colored rock materials.

The mixtures are prepared and placed in the usual way and the surface finish is secured by washing off the surface film of cement, exposing the aggregates and revealing their color. White portland cement gives the best results, particularly where light or brightly colored aggregates are used. A small amount of mineral oxide pigment may be added if desired.

Carefully selected colored aggregates exposed by scrubbing.



When forms are removed within a few hours, the surface film of cement usually can be washed off by spraying with water under pressure or by scrubbing with a stiff brush and water. When the concrete has become too hard to yield to this treatment, an acid wash of 1 part muriatic acid to 4 or 5 parts water is used. The wash is applied with a brush and scrubbed lightly into the surface until the film of cement has been removed. The surface is thoroughly washed with clean water immediately afterward to remove all traces of the acid.

A wide variety of colors and textures may be secured by exposing the aggregates. Different combinations of the materials produce different effects. A mix of yellow and white marble chips or of gray granite screenings and black crushed slag with a little mica-spar are examples of possible variations.

In producing special finishes of exposed aggregate, a mix containing approximately 1 part portland cement, 1½ parts of fine aggregate and 2½ parts of coarse aggregate made up of crushed granite, or other stone which may be desirable and suitable, is used for the facing or topping. For floors and similar work, the construction is practically the same as for two-course integral or two-course work as discussed under "Placing Colored Concrete", page 45, with the special aggregate mix as topping.

For walls and other vertical work, the special aggregate finish is made by placing about 1 in. of facing material against the face form when the backing of ordinary concrete is placed, care being taken to see that the facing is placed in a manner that will insure its bonding with the backing. The level of the facing material usually is kept a few inches higher than the backing. When special metal or wooden molds are used to hold the facing concrete while the backing is placed, the mold is withdrawn before initial setting occurs.

Finishes Imparted by Forms

Surface finishes imparted to the concrete by the forms may be smooth, rough, paneled or fashioned in almost any manner desired. It is best to construct forms of such dimensions and shapes as will make their removal easy without undue hammering and without prying against the face of the concrete. Small openings in the forms may be pointed flush with stiff clay or plaster of paris to prevent leakage or the formation of fins.

The use of screws will often help in the removal of forms and will make possible a minimum amount of

Interesting lines in this modern office were imparted by the forms.

prying with the least possible damage to the surface. Considerable skill is required to set form panels in place, plumb and properly aligned, and to fasten them so there will be no movement under the pressure of the concrete. Any movement between panels will produce ridges. Despite first-class workmanship such ridges sometimes occur. It is well to build form panels of such sizes and shapes that any form lines will harmonize with the design.

Face forms are removed as soon as practicable to permit effective repair work. Any objectionable projections are removed at this time. Voids or damaged places are cleaned, filled with a mixture of the same composition as that used in the surfacing, and covered to permit proper curing. A wooden spatula or float is used to finish such patched areas. The use of a steel trowel is not recommended.

Treatments After Concrete Hardens

Rubbed Finish. Decorative treatments which may be produced after the concrete has hardened include finishes developed by rubbing, scrubbing, sandblasting, tooling and bush hammering.

In producing the "rubbed finish", forms are removed as soon as possible. The surface is then wet thoroughly and scrubbed with No. 20 abrasive stones while the concrete is still "green". The lather that works up on the surface is removed by brushing and washing. Small voids in the surface are filled with a mortar composed of 1 part portland cement and 2 parts of the same kind of sand as was used in the facing concrete. This mortar is worked into the face with the abrasive stones so that no appreciable thickness of coating remains. A coating of any appreciable thickness is to be avoided as it may peel off and crack.

Several months after the first rubbing and when the concrete has attained a considerable degree of hardness, the surfaces again are rubbed down. This time No. 24 abrasive stones and water are used. Again a lather will be worked up which is removed with a clean wet brush. This amount of rubbing produces an attractive surface but it usually does not remove form marks.

Scrubbed Finish. To produce a "scrubbed" or "brush" finish, the forms are removed while the concrete is still quite "green" and the surface is scrubbed with wire brushes, water being used freely. The scrubbing is continued until the surface film of mortar is removed and the aggregate is uniformly exposed. The surface is then rinsed with water. If parts of the surface have become too hard to scrub in equal relief, diluted muriatic acid (1 part acid to 4 or 5 parts water) may be used. Remove all acid with clean water after scrubbing, to prevent further action.

The best time to begin scrubbing is learned by experience. If begun too soon, unsightly voids may be made by scrubbing out pieces of aggregate. If the scrubbing is not started soon enough, the concrete will be so hard that the brush will not remove the surface mortar.

It is almost impossible to obtain sharp corners in scrubbed work and for this reason fillets of rounded moldings usually are placed in the forms so as to leave no sharp corners.

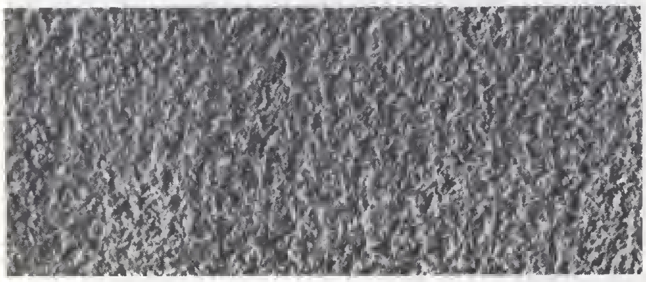
Exposing aggregates by scrubbing with a stiff wire brush and water.

Sandblast Finish. Another method used to expose the aggregate is sandblasting the surface with hard sand until the desired degree of relief is obtained. A concrete surface thus treated must have become fairly hard. The equipment necessary for sandblasting is large and therefore this treatment is seldom used on small jobs

because of comparatively high cost.

Tooled and Bush-Hammered Finishes. The surface resulting from tooling or bush hammering is very attractive because this method not only exposes tbe aggregate but also cuts it. The cut aggregate, when properly selected for texture and grading, gives sparkle to the surface and life to the finish.

The concrete, of course, must be thoroughly hard before tooling or bush hammering is begun. The bull point used in tooling may be operated either mechanically by an air or electric hammer or by hitting with a hand hammer. The texture obtained by tooling is used to best advantage on large work.



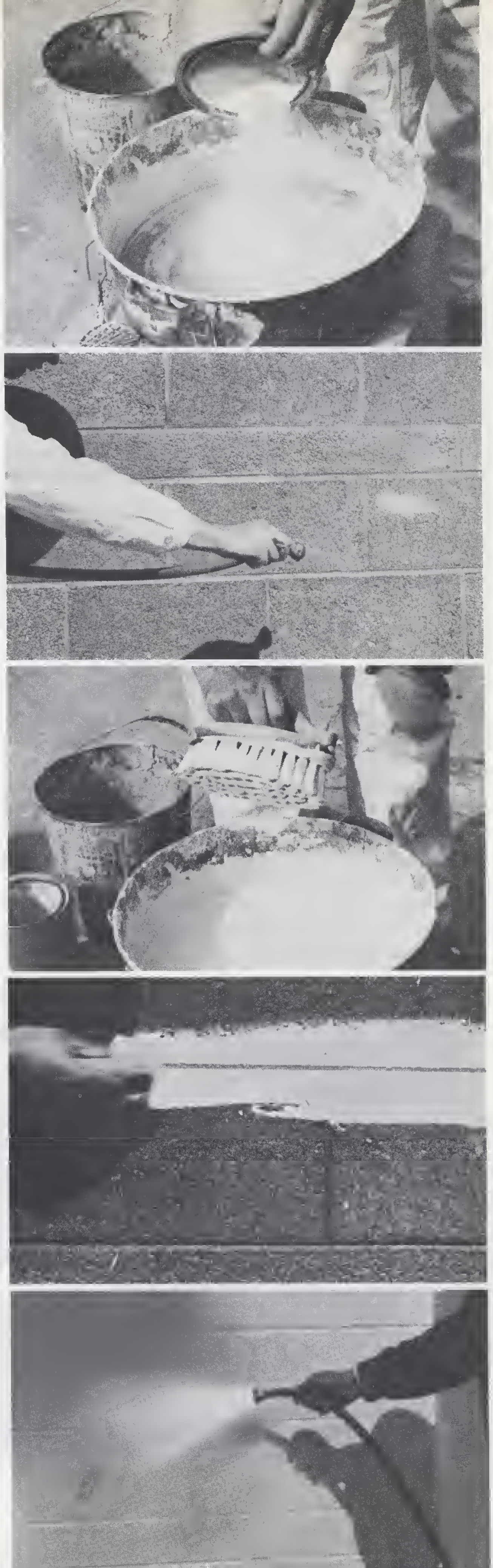
Wall finish produced by bush hammering.

Bush hammering and tooling present difficulties at corners, because it is almost impossible at such places to prevent chipping out of pieces of concrete, leaving ragged, unsightly corners. To prevent this difficulty, corners can be given a "rubbed finish" and the hammering stopped at a sufficient distance from the corners to leave a smooth marginal draft line of a width that will be in scale with the panel that is being treated. This often leads to laying out the panels in such sizes as will be best fitted for treatment by hammering.

Portland Cement Paint

Portland cement base paint is often used as a decorative treatment on concrete walls. The paint coatings emphasize rather than conceal the interesting textures and markings of concrete surfaces.

Portland cement paint is available in different colors, with lighter tints generally preferred. It can be purchased from paint dealers. Delivered in powder form, it is mixed with water on the job. It is usually applied in two coats, a first or seal coat and a finish coat. The surface to be painted is dampened with water just before painting is begun; the paint is scrubbed into the surface witb a brush baving short, rather stiff fibers; the painted surface is kept moist for 48 hours following application of each coat. Directions for preparing,



Portland cement paint is available in many colors. Steps in painting with portland cement paint: (1) Paint is mixed with water. (2) Wall surface is well dampened with water before paint is applied. (3) Ordinary scrub brush is used for applying paint. (4) Joints are covered first, after which area between joints is covered. (5) Two coats are applied. After application of each coat, paint is kept damp for 24 hours.

Vertical lines in the concrete wall were made by placing strips or inserts in the forms. The wall was finished with a light coat of white portland cement and sand grout.

applying and curing portland cement base paints are usually supplied by the manufacturer and these instructions should be followed.

Portland Cement Stucco

Portland cement stucco is frequently used to finish concrete walls. It bonds readily to concrete masonry walls which have an open texture. It also bonds firmly to cast-in-place concrete walls having rough surfaces. When such surfaces are not rough they can be prepared for stucco by roughening with bush hammers or other tools, by washing with muriatic acid and water (1:6 solution) or by dashing on the first coat of stucco.

Portland cement stucco can be given many different types of finishes from smooth to rough and with varying surface marking and textures. Further variation is obtained by use of color in the finish coat. In the hands of an experienced craftsman portland cement stucco is beautiful and serviceable wall finish.

Recommended practices for the preparation and application of portland cement stucco will be sent free on request to persons in the United States and Canada by the Portland Cement Association, 33 West Grand Avenue, Chicago 10, Illinois.

One of many pleasing finishes with portland cement stucco.

Questions

1. For portland cement stucco or watertight mortar, what mix is recommended?
2. How can mortar be colored?
3. How can attractive surfaces be obtained in concrete work?
4. What effect has sandblasting on concrete which has not fully hardened? Why is it done?
5. What are the requirements of color pigments for concrete work?
6. What precautions should be observed in placing colored concrete?
7. How can forms be used to produce special finishes?

On the farm, as well as in the city, attractive concrete houses offer comfortable living.

CHAPTER 8

CONCRETE MASONRY CONSTRUCTION AND CAST STONE

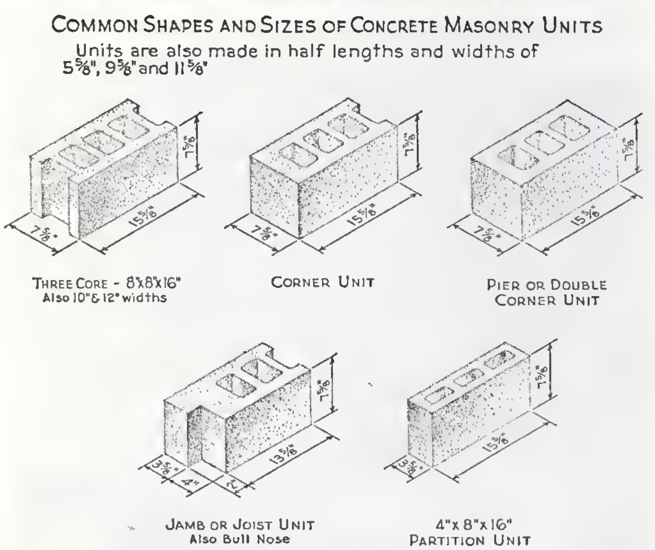
Concrete masonry construction is a term commonly used to denote an assembly of precast concrete units in building construction. Practically every community is within trucking distance of a plant where these building units are made or a material yard where they are carried in stock.

Sizes and Shapes

Concrete block are made in several sizes and shapes. The 8x8x16-in. size is probably the most widely used. When laid up in single thickness it produces an 8-in. thick wall with courses 8 in. high. One 8x8x16-in. block takes up the same space as 12 brick—the height of the block equaling the height of three courses of brick. Block are also made in 4-, 10- and 12-in. widths.

A block ordinarily spoken of as being 8x8x16 in. actually measures 7⅝x7⅝x15⅝. It is made this size so that when laid in a wall with a ⅜-in. thick mortar joint, it will occupy a wall space 16 in. long and 8 in. high. Half-length block are generally available, making it unnecessary to cut full-length units on the job if the wall is designed so width and length as well as distances between doors and windows are equal to a given number of full- and half-length units. For example, a wall exactly 24 ft. long will take 18 full-length 16-in. block in each course; a wall 26 ft. long will require 19 full-length and no half-length block.

Some representative types of concrete masonry building units.



Concrete block are made with cores or air spaces which occupy 45 to 55 per cent of the total volume. These cores lower the block's conductivity of heat, thereby making a warmer wall and also effecting a saving in materials and providing a lighter, more easily handled unit.

In addition to half-length units, most manufacturers and dealers handling block furnish corner block, door and window jamb block, sills, lintels, and other concrete specials. These enable the mason to lay up the wall more rapidly and turn out a neater job.

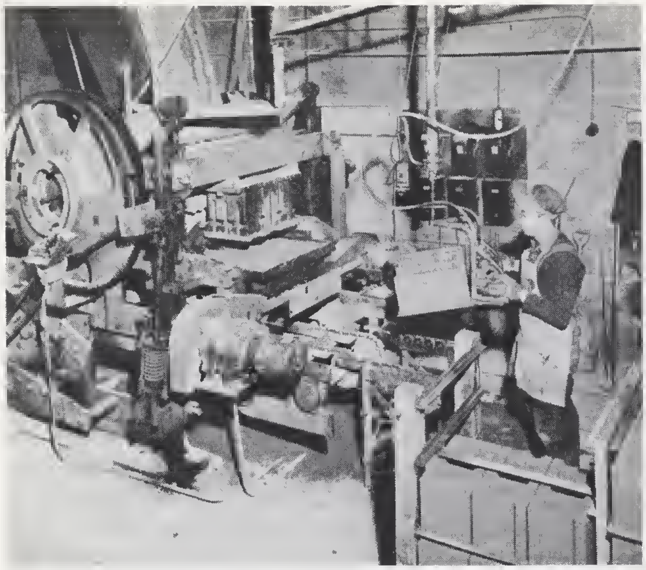
In some sections of the country, especially in the southwest, smaller sized block are quite common, such as the 5x7¾x11¾-in. and 3⅝x7¾x11½-in. or 12-in. sizes.

Concrete brick are available for those desiring brick-size units. These are made in the customary 2¼x3¾x8-in. size.

Manufacturing Block

The materials used in the manufacture of concrete masonry units are portland cement and fine and coarse aggregates. Units made with aggregate such as sand and gravel or crushed stone are called heavyweight units. Those made with expanded clays or shales, expanded slags, cinders, or pumice, for example, are termed lightweight units. The maximum size of aggregate rarely exceeds about ½ in. and should always be less than half the thinnest wall or web section. For special surfaces and finishes, various kinds and types of aggregates are used similar to those described in the preceding chapter under "Special Surface Finishes".

Three methods commonly used in the manufacture of concrete masonry units are: tamping, in which the materials are mixed to a semiwet consistency and then tamped in the molds; vibrating, in which a fairly stiff



A concrete block machine capable of producing 600 8x8x16-in. block per hour.

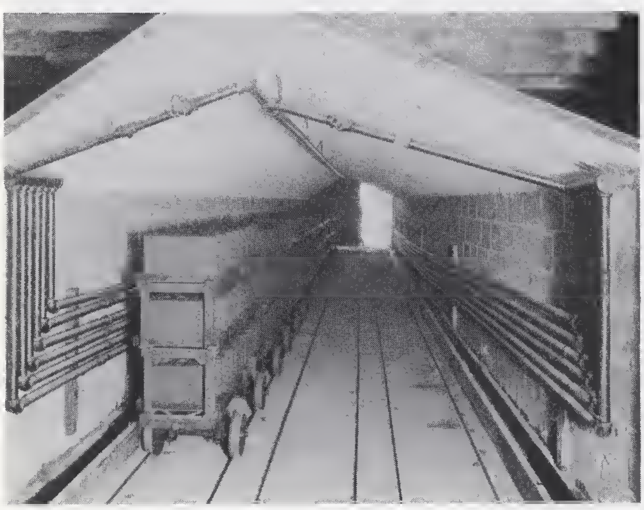
mix is consolidated in the molds by vibration; pressure, in which the concrete is placed in the molds and compacted by pressure.

The units are removed from the molds on pallets immediately after compaction and placed in a curing kiln where the temperature is kept from 110 to 165 deg. F. Here heat and moisture speed up bardening. After removal from the curing kiln, the masonry units are stored and dried for several weeks before they are used.

Concrete masonry units should meet the strength, moisture content and absorption requirements of building codes.

Some more common uses of concrete masonry units are for construction of walls for basements, stores, residences, barns and silos; partitions, and in almost any place where a tight, durable, fireproof wall or partition is desired.

Concrete block are moist cured in a heated kiln.



Masonry Wall Construction

Mortars should be made with clean, well-graded sand and clean water.

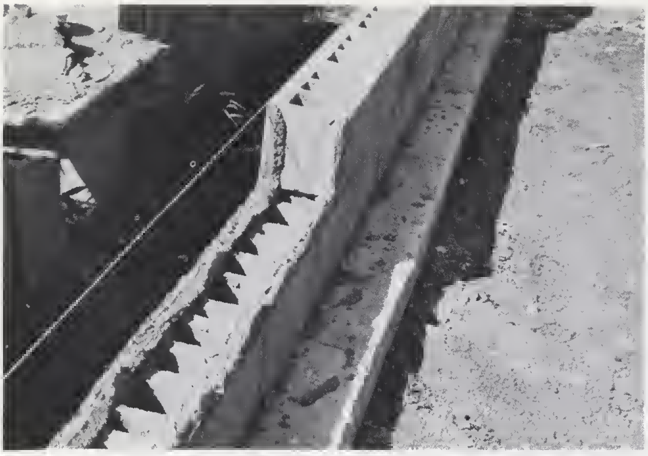
For laying concrete masonry walls subject to average loading and exposure, use a mortar made in the proportions of 1 volume of masonry cement* and between 2 and 3 volumes of damp, loose mortar sand; or 1 volume of portland cement and between 1 and 1¼ volumes of hydrated lime or lime putty and between 4 and 6 volumes of damp, loose mortar sand. Walls which will be subjected to extremely heavy loads, violent winds, earthquakes, severe frost action or other conditions requiring extra wall strength, including isolated piers, should be laid with a mortar made of 1 volume of masonry cement* plus 1 volume of portland cement and between 4 and 6 volumes of damp, loose mortar sand; or 1 volume of portland cement, to which may be added up to ¼ volume of hydrated lime or lime putty, and between 2 and 3 volumes of damp, loose mortar sand.

Mortar should be mixed thoroughly with just enough water to give the desired plasticity and workability. Thorough mixing improves the plasticity of mortars. Less mixing water is required to obtain a workable consistency when time of mixing is increased.

Mortar is commonly mixed by hand, although machines are sometimes used for this purpose. Tools required for hand mixing are hoe, shovel and mortar box. Cement and sand are mixed together dry. If hydrated lime is used it can be mixed in with the cement and sand. When lime putty (slaked lime) is to be used, the lump lime is dissolved in water to a creamy consistency and is then added to the previously mixed cement and sand. Mix only enough mortar at one time so that the entire batch can be used before it begins to harden. Mortar tbat has partly set should not be used.

*Federal Specifications SS-C-181 b, Type II.

A plastic workable mortar is used in laying concrete block.



Mortar is placed on block in parallel strips known as face-shell bedding.

Colored mortars can be produced by following the instructions given for coloring concrete.

The concave type of mortar joint is usually preferred. It is made by drawing a rounded or V-shaped pointing tool along the joint after the mortar begins to stiffen. This operation compacts the mortar and produces a tight, water-resistant joint. Both vertical and horizontal joints are made $\frac{3}{8}$ in. thick. When the wall is to receive a portland cement stucco finish or is to be plastered, the mortar is struck off flush with the wall.

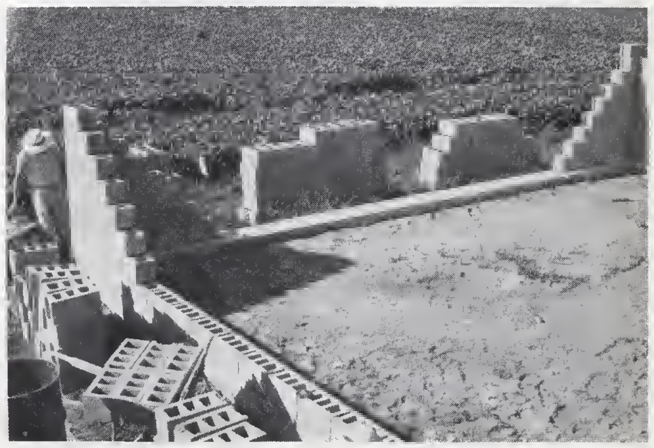
Two men generally work together in laying concrete block. One man, called a helper, prepares mortar and brings it within easy reach of the mason, who lays the block. The mortar is brought either in a hod which is carried on the shoulder or in a pail carried by hand. The hod is convenient when mortar is to be carried up a ladder. However, pails may be used and a rope and pulley arrangement devised to raise mortar to the scaffold. The mortar is dumped upon a mortar board or laying board, a board platform about 3 ft. square.

Corner block are usually set first and chalk lines stretched tightly between them to serve as a guide in building a straight wall. These lines should be of stout cord such as cotton. Binder twine is worthless for this work. If the corner block are accurately placed and plumbed, the line kept taut and the block laid to the line, the wall will be plumb and true.

Jamb block are used at door and window openings. After the wall has been constructed the frames for such openings are placed in the recess provided by the jamb block. Jamb block are often used at floor levels, the recess at the end of the block providing notches for the floor joists.

Plates and sills are attached to concrete masonry walls with bolts placed at intervals of 4 ft. apart or less and extending through at least the top two courses. Anchorage is secured by slipping a large washer on the bolt and filling around the latter with concrete.

Concave or V-shaped mortar joints are made by drawing a pointing tool along the joint after mortar begins to stiffen.



Corners are built up first.

Surface Finishes

Concrete masonry units are usually made with flat or straight faces. Face texture may be regulated from fine to coarse by changing the proportions of fine and coarse aggregate in the concrete mix. Another method of providing face textures is to use a fine water spray or to brush the faces of the units with a wire or bristle brush immediately after molding.

Special facing treatments are provided by using a special facing mix containing either mineral oxide pigments or colored aggregates or both. The colored aggregate may be exposed by scrubbing the faces of the block with a wire brush and water soon after they are made.

Concrete masonry walls are generally painted with two coats of portland cement base paint, which is scrubbed into the faces of the units with a brush having short, stiff bristles. Portland cement paint is sold

Left—A neat concrete masonry wall. *Center*—An attractive finish produced by tooling the horizontal joints to make them stand out prominently. *Right*—Different course heights are used to give this wall an interesting finish.

in powder form and is mixed with water to a creamy consistency before applying. A wide variety of colors is available. Sometimes fine silica sand is added to the paint to give the wall surface a sanded texture.

Another facing treatment is the use of portland cement stucco on the concrete masonry wall. A wide variety of colors and textures is available. The texture of the concrete masonry and the natural affinity of the portland cement in the stucco for that in the concrete units make this an ideal stucco base.

Interesting wall finishes can be obtained by varying the treatment of the mortar joints. A simple yet attractive finish is produced by tooling the horizontal joints to make them stand out prominently, cutting off the vertical joints flush with the wall surface, and then rubbing the vertical joints with a piece of carpet, cork or other rough material to give them about the same texture as the concrete masonry units. Then when the wall is painted with portland cement paint the attractive finish with bold, horizontal lines shown in the illustration is obtained. Other variations in wall finishes are obtained by using block of two different heights, laying them in alternate courses or laying them in any one of the many other patterns possible.

Cast Stone

Cast stone is the term applied to building stone manufactured from concrete. By making the forms to the proper shape and using selected aggregate, almost any desired effect can be secured. Molds for cast stone may be constructed of metal, glue, plaster of paris, wood or sand, whichever is most desirable for the work.

The operation of casting concrete in sand is similar to that of casting iron. The pattern is made of wood of the exact size required. It is then molded in sand exactly as iron is cast. A concrete mixture of wet consistency is poured into the mold. Generally the casting is left in the sand for three or four days and after being taken from the sand is allowed to harden in the air before being finished.

Wood molds consist of side planks and end pieces resting on a pallet and held together by clamps. In tamped work, the facing mixture, if one is used, is placed in the bottom of the mold, up to the front and part way up the ends, as desired, and then the backing mixture is added and tamped. The concrete is struck off smooth at the top, a layer of bedding sand added, and a plank placed on top of the sand and clamped in place. The entire mold and contents are turned over, so that the piece is right side up when the mold is removed. When the concrete has hardened sufficiently, the mold pieces are removed, and the cast stone left right side up on the plank.

In the wet cast method, a smooth concrete floor or table top is shellacked and oiled, and the form pieces erected thereon, with the necessary insert pieces and

Making cast stone. Intricate design can be obtained.

dividers. A concrete of quaky consistency is used, and it is left in the molds until it has thoroughly hardened.

Various metal molds are now made for different ornamental pieces and standard architectural units. These molds need only be cleaned and oiled, and can be used many times. When necessary, the individual pieces (such as lintels) may be reinforced.

Plaster is used extensively for making models and molds for ornamental cast stone. Skilled workmen can make a suitable plaster model from an architect's drawings. When a plaster model is finished, it is shellacked and oiled, and a mold made over it. The model is removed from the mold and the mold surface shellacked and oiled before the concrete is added. With plaster molds, the concrete mix may be of pouring consistency or may be quite dry and lightly but firmly tamped in the mold. Draw molds may be used when there is no undercut or when the undercut sections of the mold are made so that they will readily separate from the main part, and can be removed easily after the main part of the mold has been drawn. Draw molds must be smooth and trim, and tapered a little so they can be withdrawn without injuring the concrete. Plaster molds may be used several times.

Gelatin or glue molds should be used where there is much undercut which would necessitate making a plaster mold in many pieces. In making a glue mold, the model is first covered with paper and a thin layer of modeling clay added. This clay covering is greased and plaster added over it to form a shell with several holes or air vents. When the plaster mold is hard it is removed, and the clay and paper cleaned from the model. The surfaces of the model and mold are shellacked and oiled; the model is placed in the mold, and the space between filled with hot glue. Air vents can be stopped with clay as the space is filled. When the glue is hard (about 24 hours) the plaster mold is first removed and the glue mold is cut into a few parts and removed from the model. Concrete of pouring consistency must be used with a glue mold because in it concrete cannot be tamped. A glue mold can be used about four times, after which the glue may be remelted and used again.

Sometimes various combinations of molds are used, such as wood strips in plaster molds and plaster inserts in wood molds. For difficult ornamental work, when much duplication is necessary, a glue mold is first made, then a glue model, and then several plaster molds from the glue model. When there is much undercut, the plaster mold is cut away from the concrete and discarded.

Molding sand should be a fine sand which will mold well when wet. The sand is often mixed with fine loam or plaster, and sometimes with an integral waterproofing powder. The sharp edges in the mold may be built up of wood inserts because the sand edges may crumble. As sand tends to stick to concrete surfaces, it is always necessary to give this type of cast stone some surface treatment.

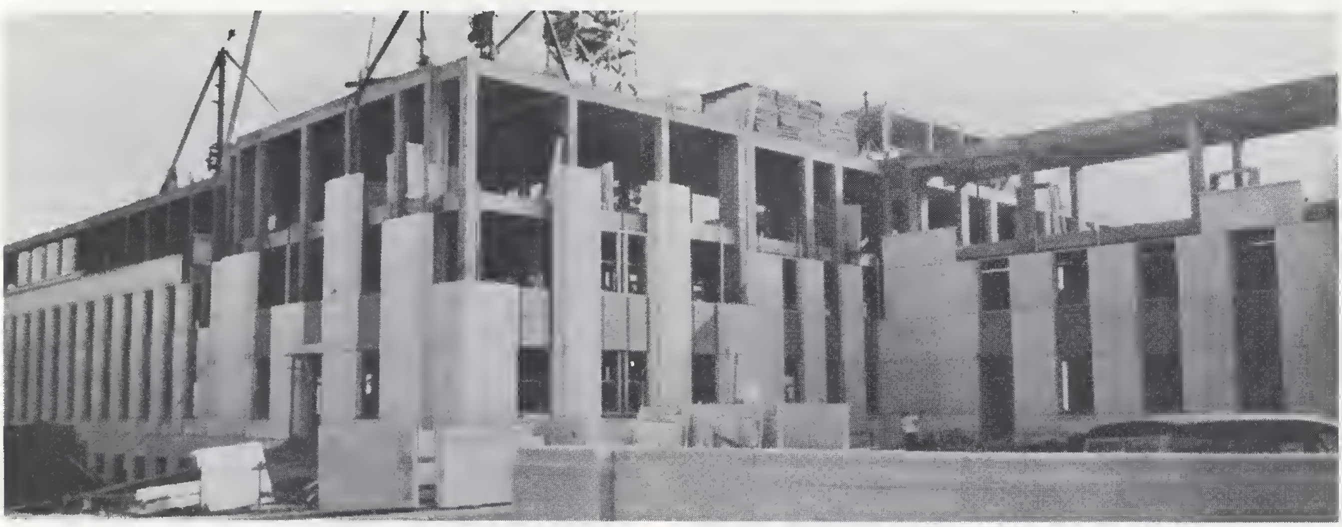
Although most cast stone is made of the same mix and material throughout, it is very easy to provide facing mixtures, especially in the tamped method.

Color effects may be produced by the use of mineral pigments as previously described.

Questions

1. For what types of construction are masonry units suitable?
2. What advantages are gained by making air spaces in a masonry wall?
3. What are the requirements of a good mortar?
4. In what type of cast stone work is a glue mold required?

Cast stone is widely used for exterior and interior ornamentation.



CHAPTER 9

REINFORCED CONCRETE

Reinforcement is the term used to describe the steel bars or mesh placed in concrete, usually to increase its tensile strength. Concrete is a material which is very strong in compression, that is, in bearing loads that are placed directly upon it; but it requires steel bars or other metal reinforcement in some structures to increase its resistance to stresses or forces that tend to bend or pull it apart. In a concrete lintel over a door or window opening or in a beam, for example, reinforcement is placed near the lower side, as that is the side which tends to pull apart when the lintel or beam is loaded.

In some cases, such as concrete fence posts where the load may be applied from any direction, it is necessary to reinforce all portions which may be subjected to tensile stresses. Long beams, such as those supporting the mow floor of a barn which extend continuously over a number of columns or other supports, may be subjected to negative bending or tension on the upper side over the supports. In this case, reinforcement is placed in the upper portion to carry the tensile stresses. Reinforcement is also placed in the lower portion of the beams to take care of the tensile stresses occurring in the beams between supports.

Where space limits the size of the beam and the loads are such that concrete alone is not adequate, it is also customary to use steel to increase the compressive strength. Steel is very strong in both tension and compression. Moreover, steel and concrete have approximately the same coefficient of thermal expansion so that no difficulty is experienced because of difference in expansion and contraction of the steel and concrete.

Steel rods or mesh are often used in walls, floors, etc., to prevent cracking which would otherwise result from wide temperature changes. For example, a feeding floor exposed to the elements will become quite hot in summer and cold in winter. These changes in temperature result in expansion in summer and contraction in winter. Being strong in compression, the edges are pushed outward, sliding over the soil, in summer. The tensile strength of the concrete, however, may be inadequate to pull the edges back in winter. Cracking results. Suitable reinforcing, usually wire mesh, will supply the necessary tensile strength and hold the slab together.

Simple reinforcement in a beam may consist only of straight bars extending from end to end and placed far enough from the surface to provide a satisfactory thickness of concrete around each bar to enable it to function as intended. The value of such a bar can be increased by bending it at the ends to prevent its slipping through the concrete should the bond between steel and concrete prove inadequate. Deformed bars with raised portions to increase the friction between the concrete and steel are often used.

Reinforcing bars should be accurately placed. Here bars are laid on slab bolsters which support bars about 1 in. above the forms.

Concrete is placed under and around all reinforcement to obtain a good bond between concrete and steel.

A system developed in Germany employs a thin shell of concrete, heavily reinforced. Here a large airplane hangar is constructed with this system.

Usually, however, reinforcing bars are not straight throughout their length but bent so as to resist the stresses set up in the beam more effectively than they would if straight. Stirrups or other devices may be used to resist shearing stresses.

On the whole, the determination of stresses on a beam or other structural element, the selection of bar size and number and proper shaping of bars introduce so many complicated and technical problems that the job of designing should be entrusted to an engineer experienced in reinforced concrete design.

Reinforcement should be free from rust, scale or other coatings that will reduce the bond between the concrete and the steel. It is necessary to clean bars or metal reinforcement which do not meet this requirement. Bending or straightening reinforcement in a manner that will injure the material is to be guarded against. Heating of reinforcement is likewise not advisable. No. 18 annealed wire usually is used to tie reinforcement together where it laps and intersects.

Reinforcement should be accurately placed and secured, and be supported by concrete or metal chairs or spacers or metal hangers. Ordinarily, reinforcement is placed after form work is built.

In general, it is recommended that all reinforcement be protected by at least a ¾-in. covering of concrete. In placing concrete, it is desirable to work the material around and under all reinforcement and embedded fixtures, working the concrete with suitable tools. Where conditions make spading difficult, or where reinforcement is closely spaced, batches of mortar containing the same proportion of cement to sand as used in the concrete are first deposited in such locations. Then the form is filled with the specified mix. Special care is taken to spade and tamp the concrete around the reinforcement. Tapping the form with a rubber or wood mallet or any similar practical method may be used to make the concrete settle around and under reinforcement. Specifications usually limit the maximum size of aggregate to ¾ of the minimum spacing between reinforcing bars.

Reinforced Concrete Beams (*Demonstration No. 12*). A good demonstration can be carried on in the school shop to illustrate the effectiveness of reinforcing as well as the proper location for it. Use the same molds and testing machine as have been previously suggested for demonstrating the effectiveness of the water-cement ratio. Make several beams with the reinforcing bars located near the bottom of the beam, another group with the bars midway from top to bottom, and a third with the bars near the top. The reinforcing bars must extend the full length of the beam. For this purpose they can be located by first filling the mold to the height desired for the reinforcement and completing the filling after the bars are in position.

Questions

1. What is reinforced concrete?
2. When is reinforcement necessary?
3. Would you reinforce a fence post? A barn foundation? A sidewalk? A flat concrete roof?
4. Where should reinforcement be placed in a beam?
5. How can one insure getting concrete into all corners and around the reinforcement?
6. What materials are suitable for reinforcement? Why?

Heavy airplanes require smooth, substantial runways such as this one made of concrete.

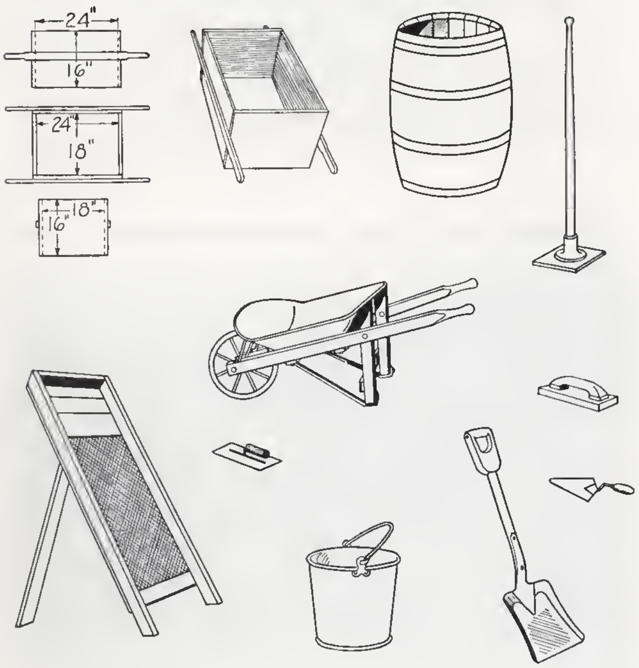
CHAPTER 10

EQUIPMENT

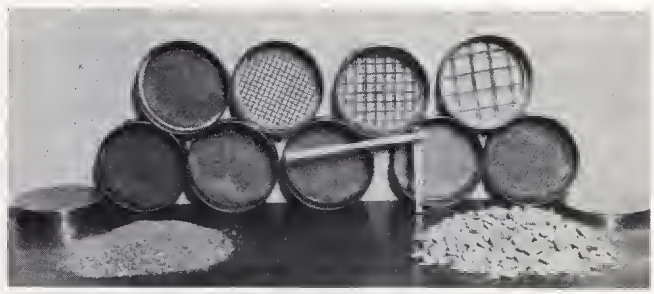
Equipment for a course in concrete is needed for laboratory tests and for concrete construction in the field.

Laboratory Equipment

Insofar as possible, laboratory work has been planned to use equipment ordinarily found in a school's agricultural or physics laboratory. Some additions easily may be obtained or the skillful teacher often can modify the work slightly to use other equipment. Standard testing sieves are made so that the openings in any screen are just half as large as those in the next larger size and twice as large as those in the next smaller size. Some variations in the manufacturer's listing of the number of meshes in the smaller sizes may mean that one manufacturer has used a larger size wire in the screen. A customary designation is ¾ in., ⅜ in. 4, 8, 14, 28,



Typical equipment for concrete work in the field or school shop.


A standard set of laboratory sieves.

48, 100, 200. Soil-testing sieves with different grading may be substituted if the results are modified accordingly.

Other laboratory equipment needed follows:

Pans
Graduates (500 cc.)
Scales
12-oz. prescription bottles
Quart fruit jars
Pieces of window glass (9x12 in.)
Slump cones

Field Equipment

Most tools required in concrete work are simple and many of them can be homemade.

The principal ones are the following:

1. Screen
2. Mixing platform
3. Square pointed shovels
4. Measuring box
5. Water barrel
6. Pails
7. Hose
8. Tamper
9. Spading tool
10. Strikeboard
11. Wood float
12. Steel trowel
13. Edger
14. Groover
15. Wheelbarrow
16. Small wire brushes
17. Straightedge
18. Measures (gallon and quart)

A *sand screen* should be about 3x6 ft. The frame can be made of 2-in. lumber, 4 to 6 in. wide. Legs should

For hand-mixing, a firm, tight platform is necessary.

be so attached to the sides that the screen can be set at the desired angle while material is thrown upon it to separate the sand from the gravel. This angle should be about 45 deg. A piece of wire cloth or fabric having 3 meshes to the linear inch should be nailed to the frame. Material to be screened is thrown with a shovel against the upper portion of the screen and, as the coarse aggregate rolls down, it is separated from the fine aggregate.

For hand-mixing, a watertight *mixing platform* at least 7x12 ft. should be provided. A platform of this size is large enough to permit two men using shovels to work upon it at one time.

The platform can be made of 1-in. tongue-and-groove lumber nailed to 2x4-in. stringers placed about 2 ft. apart. Strips of 2x4-in. lumber nailed to 3 sides will keep the material from being shoveled off while being mixed. Covering the platform with galvanized sheet metal facilitates mixing and adds to the life of the platform.

The *measuring box* is necessary to measure exact quantities of sand and gravel or crushed stone. Such a box is a bottomless frame made of 1- or 1½-in. material and should have a capacity of not less than 1 cu.ft. If larger, it should be of 2- or 3-cu.ft. capacity and should be marked on the inside to show levels at which volume will equal 1 cu.ft., 2 cu.ft., etc. Handles on the side of the box make lifting easier after the material required has been measured.

DIMENSIONS FOR BOTTOMLESS MEASURING BOXES

Capacity in cu.ft.	Inside measurements in inches		
	Length	Width	Height
1	12	12	12
1½	15	15	11½
2	18	18	10⅝

Ordinary square pointed *shovels* are used for mixing concrete.

A *wheelbarrow* facilitates transporting concrete from the mixer or platform to the place of final use. A rubber-tired, metal wheelbarrow having a body with the front higher than the back to prevent loss of concrete when the barrow handles are raised is generally used.

Concrete placed in forms must be spaded or tamped. A *tamper* is used when concrete is placed for sidewalks, floors or other flat surfaces. It may be made by boring a 1½-in. hole in the end of an 8x8x12-in. piece of timber and inserting a handle about 4 ft. long. A metal tamper may also be used, or one can be made of concrete.

A *spading tool* of some kind is necessary to settle the material in the forms properly and also to secure a surface finish free from stone pockets. Such a spading tool may be made by flattening an ordinary garden spade or by straightening an old garden hoe. Both tools are used by working them up and down in the concrete close to the form faces to force back coarse particles and bring sand-cement mortar to the form face.

Sometimes a chisel-edged board 4 to 6 in. wide may be used for spading concrete, the upper end being shaped to form a convenient handle. When reinforcing metal is placed in the concrete, smaller spading tools will be needed to work in the smaller spaces. Pointed sticks, steel rods or narrow chisel-edged pieces of wood are used for this purpose.

A *strikeboard* is usually a piece of 2x4-in. lumber, long enough to rest across the top of the form, as in sidewalk construction, so that the top of the concrete can be approximately leveled before final finish.

A *wood float* is used to finish the surface of the concrete after it is struck off, as in building walks, pavements and floors.

A bottomless measuring box.

A groover is used to mark off divisions in a concrete walk, driveway or other flat surfaces.

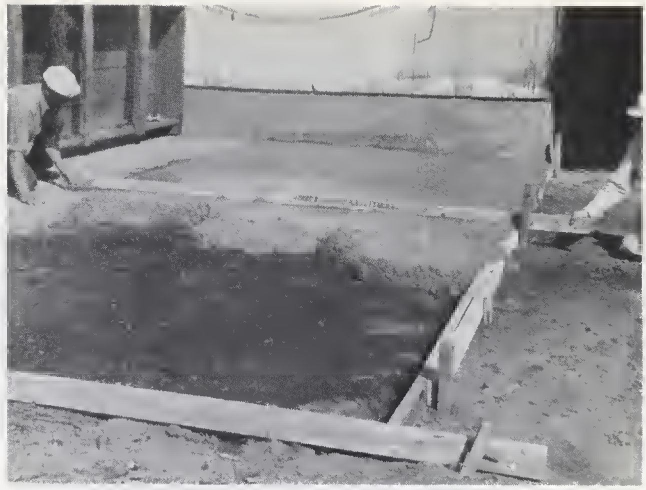
A *steel hand float or trowel* may sometimes be required where a smoother surface is desired than can be obtained with the wood float.

For finishing joints between slabs in walks, floors and similar concrete work, a tool known as a *groover* is used. To finish the edges of the slabs a tool known as an *edger* is used.

A *water barrel* and *pails* are necessary to add the required amount of water to the correctly measured materials.

Most of the batch *mixers* in use have revolving drums with fixed blades inside, although a few have fixed drums with revolving blades or paddles. The latter type is commonly used in block manufacture where dry mixes are employed. Concrete mixers should be run at speeds recommended by the manufacturer. Batches should not be larger than the rated capacity of the mixers.

Concrete is mixed quickly and thoroughly by machine.



A strikeboard or screed is used to level off the freshly placed concrete.

Supplementary Reading

In this short manuscript, the various phases of concrete construction are treated very briefly at best. Every school shop should have accessible a library of books and bulletins covering the many phases of this work.

Various text books on cement and concrete should also be included in the library.

Usually single copies of government and college publications may be obtained for the asking. The Portland Cement Association has also published many pamphlets and booklets having a direct bearing upon various types of concrete construction. Information and literature on specific subjects will be furnished free on request in the United States or Canada.

Specifications and tests for cement and concrete may be obtained from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

A concrete garden pool enhances beauty of this backyard.

CHAPTER 11

PROJECTS AND PROBLEMS

Principles learned in the classroom should be applied practically by making various articles of concrete. Selection of these will depend largely on the facilities at hand and the interest of the individuals in the class.

Simple projects, preferably small in size and requiring easily made forms, should be undertaken first. Larger pieces may be used as supplementary home projects.

A few simple projects are included here. Many others are to be found in booklets published by the Portland Cement Association.

The student should be encouraged to be constantly on the lookout for other projects that will be valuable and interesting.

Laboratory directions are not given in complete detail. Any course should strive toward developing initiative and the student should be encouraged to plan his own procedure so that he will be able to do a concrete job systematically when engaged in projects outside the shop.

Principles governing each step should be referred to constantly. Not a single step should be slighted—from the selection of the aggregates to the curing of the product. Habits are being developed which may prove good or bad later according to their formation here.

Originality may be expressed in the design of a tea tile.

For smaller exercises, the cement paste should be mixed first and the sand and gravel, proportioned as recommended, added slowly until the correct degree of workability is obtained. The water-cement ratio in all exercises is given on the assumption that average wet aggregates are to be used. If the aggregates are damp or very wet, it will be necessary to alter the quantities accordingly (see Table 1, page 18).

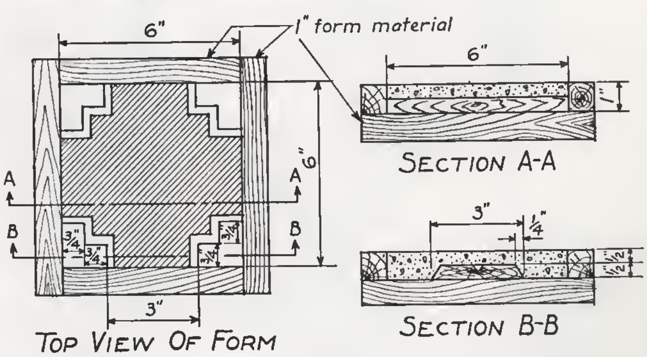
Tea Tile

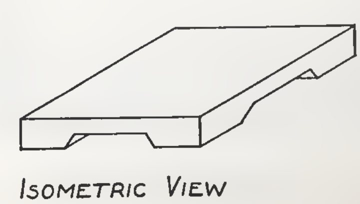
A tea tile to hold the tea pot, coffee pot or other hot dishes is a useful article for the dining table. It also permits wide variation in shape, color and design to meet varying abilities and imagination. It can be made square and simple or elaborate and decorated. Colorings as described in Chapter 7 can be used. By use of stencils and different colored mixtures, designs similar to that shown in the illustration can be produced.

To make the tea tile, assemble the form on the pallet and set the bottom form or core inside the square frame. All surfaces coming in contact with the concrete should be shellacked to produce a smooth surface. When dry, these surfaces should be oiled.

After the concrete has been placed, the top surface should be smoothed off with a trowel and the edges

Forms for making a concrete tea tile.





beveled. To remove the form, the outer frame and bottom board or pallet should be taken off first.

When the core is removed care must be taken not to injure the concrete.

A tile with a glass smooth top surface can be produced by setting the frame on a piece of glass and filling the lower part with mortar, pressing it down well. The core form is then placed so that it will be level with the top surface of the frame, care being taken to fill the corners with mortar and to smooth them off neatly.

This method is employed when two colors are used in the top. One color of mortar is first placed in a stencil cut from ¼-in. wallboard. After the stencil is removed, the form and the other color are placed.

Materials and Equipment. One-half quart of cement; ⅓ qt. water; approximately 1 qt. sand; oil; small mixing board; trowel; quart measure; form constructed according to sketch; wood or glass pallet, 8-in. square. (Note! Sand only is used as aggregate in making the tea tile. Approximately 4½ gal. of water is added per sack of cement when average damp sand is used.)

Baseball Home Plate

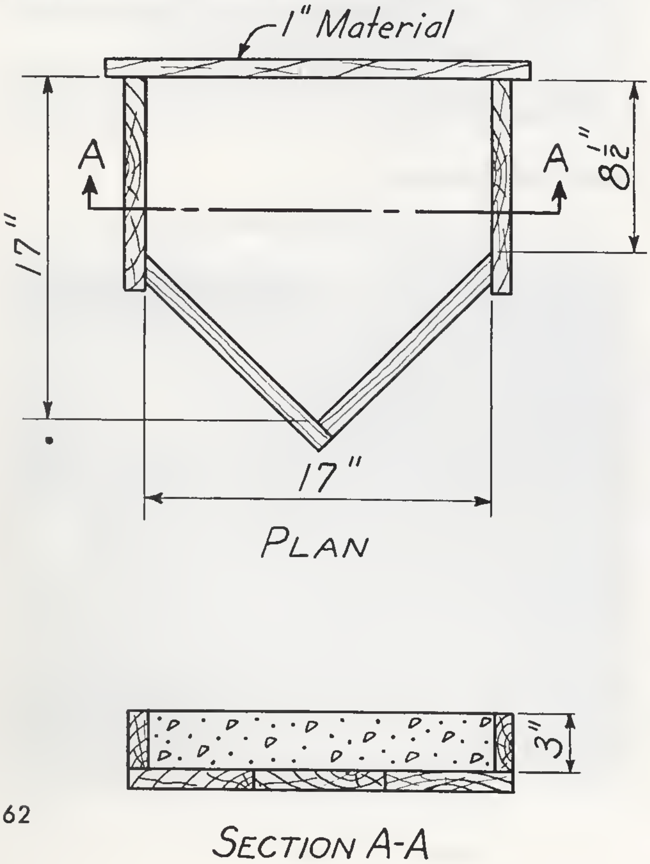
Another project which requires only simple forms and is easily finished is a baseball home plate. If it is placed flush with the ground, players will not be injured when sliding into it.

To make the home plate shown in the drawing, the form should be assembled on a piece of oiled paper about 2 ft. square, laid on a flat surface. If preferred, the home plate can be cast in place by digging a hole and placing the forms in the desired location. After the concrete has hardened, the forms may be removed and soil filled in around the base.

If desired, the other three bases can be made of concrete also.

Materials and Equipment. About ⅙ sack of cement (15.6 lb.); 4½ qt. water; ⅓ cu.ft. sand; ⅖ cu.ft. gravel; oil; mixing board; shovel; wood float; a 1x4-in. board 72 in. long to be cut as indicated in the drawing; 7d box nails. (Approximately 4½ gal. of water is added per sack of cement, using average damp sand.)

A baseball home plate can be made by using the form shown here.

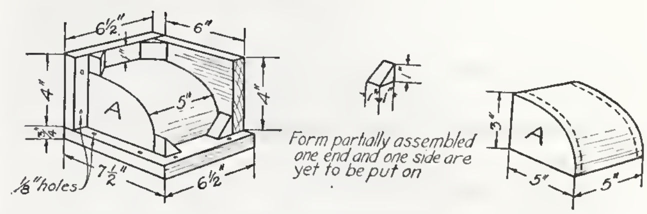


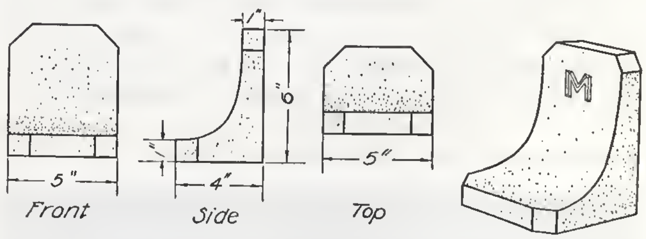
Book Ends

An almost unlimited number of designs is possible. The book ends may be made in color by adding mineral pigments to the mortar or by using special aggregates such as crushed colored marble and granite.

Letters or figures may be cast on the exterior faces by cutting forms from thin wood or fiber sheets and attaching them to the form. It must be remembered that the form should be made reversed from that

Forms for making concrete book ends





Variations in the design of book ends are limited only by the ingenuity of the student.

desired in the concrete.

The forms should be assembled with screws. Shellac all surfaces coming in contact with the mortar and oil them just before using. Trowel exposed surfaces. Any bubbles or irregularities in the book ends may be patched after removal of forms. After the book ends have cured thoroughly and dried, felt bases may be glued on.

Materials and Equipment. One pint cement; ⅗ pt. water; 1 qt. sand; oil; small mixing board; trowel; quart measure; sixteen 1¼-in. No. 10 flat head wood screws; 1 piece tin 5x8 in.; wood as required by the drawings. (Approximately 4½ gal. of water is added per sack of cement, using average damp sand.)

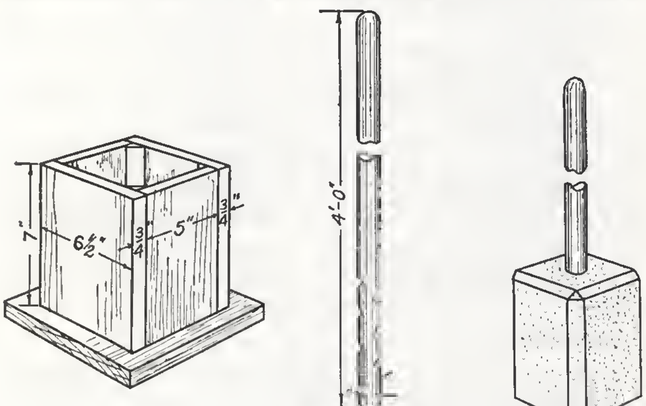
Hand Tamper

A concrete hand tamper is a practical tool to have in the home; it may be used to compact the base and subgrade for a sidewalk, a driveway or similar work.

The handle of the tamper should be held in the center of the form and about 1 in. above the pallet while the concrete is placed around it. Note how the handle is notched at the lower end and that nails are driven through it to prevent the handle from pulling out or turning. The top edges of the tamper may be beveled with a trowel.

Materials and Equipment. One quart of cement; 1⅓ pt. water; 2 qt. sand; 3 qt. gravel; oil; trowel; quart measure; wood pallet; 4 strips triangular mold; handle from discarded broom, hoe or rake; lumber as required by the drawing. (Approximately 4½ gal. of water is added per sack of cement, using average damp sand.)

Forms for hand tamper. Note method of anchoring handle in the concrete.



A hand tamper is helpful in preparing a firm base for sidewalks and driveways.

Pedestal

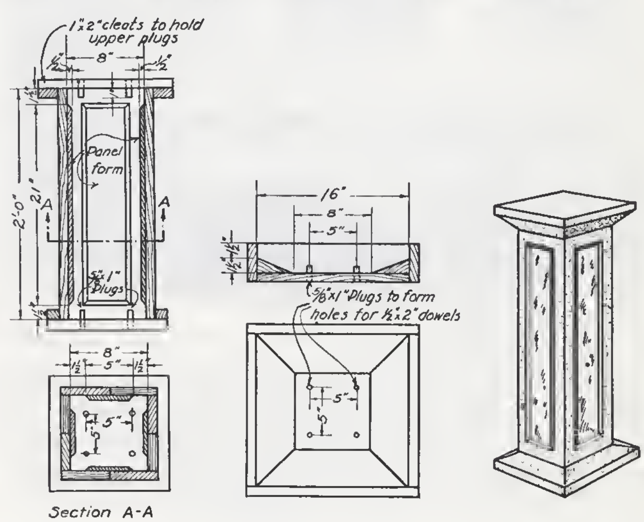
A concrete pedestal may be used for supporting garden and porch ornaments such as flower boxes, vases, sundials, bird baths and gazing globes. Many variations in design are possible. Suggestions for color or surface treatment are given in Chapter 7.

The base, top and shaft are made separately and assembled by means of dowels after the concrete hardens. The base and top are identical so they are cast in the same form. Forms should be carefully sanded, shellacked and oiled on surfaces coming in contact with the concrete. The forms should be fastened with screws to facilitate their removal from the concrete and to permit re-use. Be sure to insert plugs in the forms for making dowel holes in all three of the sections.

The pieces should harden at least 48 hours before assembling. Set the dowels in the holes provided with a medium wet mixture of cement and water. Spread a thin layer of the same mixture between the base and the shaft and also between the shaft and the top to bond the parts together. Airholes or other irregularities may be patched at this time.

Materials and Equipment. Two-thirds cubic foot of

Forms for concrete pedestal for sundial or other garden ornaments.



A sundial adds attraction to the garden.

A concrete lawn roller.

A concrete flower box.

cement; 3 gal. of water; 1 cu.ft. of sand; 1⅓ cu.ft. of gravel; oil; mixing board; shovel; trowel; 8 round metal dowels, ½x2 in.; forms constructed as shown in drawing on page 63. (Approximately 4½ gal. of water is added per sack, using average damp sand.

A concrete hog waterer makes a good class project.

A partial list of projects which can be made either in the laboratory or in the field is given below:

- flower box
- lawn roller
- shoe scraper
- chimney cap
- garden bench
- lawn and garden pool
- bird bath
- water trough
- hotbed or cold frame
- refuse burner
- sundial
- flagstone walk
- feeding floor for hogs
- barn floor and manger
- step and porch floor
- ratproofing of building walls and footings
- garden and retaining wall
- machine foundation
- watering tank
- milk cooling tank
- septic tank
- well curb and platform
- cistern
- storage cellar
- sidewalk
- driveway and approach
- paved barnyard
- basement floor

Problems

A list of problems is presented below, with the suggestion that the instructor supplement the laboratory and classroom work with regular problem assignments. The solution of problems affords a most effective means of bringing to the student an intelligent understanding of the proportioning of concrete mixtures, together with the practical experience of estimating quantities and costs.

1. How many sacks of cement will be required for a driveway using 8½ cu.yd. of concrete? How many cubic feet of damp sand will be required? How many cubic feet of coarse aggregate will be required? How many gallons of water?

2. What will be the total volume in cubic yards of concrete mixed in 23 one-sack batches if concrete is used for heavy foundation work?

3. Find the volume of concrete required in a foundation of a rectangular building 31x62 ft. outside dimensions, wall to extend from frost line to 12 in. above grade. Frost line is considered 3 ft. below grade. Wall averages 10 in. thick. Wall area of 18 sq.ft. is deducted for openings.

Hotbeds and cold frames built of concrete are rotproof.

4. Find the approximate amounts of sand, cement, coarse aggregate and water required for the foundation mentioned in Problem 3.

5. How many trips will be required to haul the cement for the foundation mentioned in Problem 3 if the wagons or trucks in which hauling is done can carry 2 tons?

6. How many square feet of sidewalk can be made per sack of cement, making the slabs 5 in. thick?

7. A tank wagon holds 20 bbl. of water. Each barrel holds $31\frac{1}{2}$ gal. How many trips will be required to furnish mixing water for 108 cu.yd. of concrete if $5\frac{1}{2}$ gal. of water are required per sack of cement and the mix is 1:3:4?

8. A circular water tank is 18 ft. inside diameter and 20 ft. in height from top footing to top of wall; water depth is assumed as 15 ft. How much water will it hold in gallons and barrels?

9. In the above tank the lower 3 ft. of wall is 8 in. thick, the remainder 6 in. The floor is 8 in. thick and is placed so that its top surface is 4 ft. above top of footing. The footing is 16 in. wide and 12 in. thick. How much cement, damp sand and coarse aggregate will be used to construct the job?

10. A concrete counterweight of 15 tons is required for a bridge. A space 10 ft. square, any height, is available. If made to occupy the 10x10-ft. space, how high will the weight be? Assume weight of concrete to be 145 lb. to the cubic foot.

11. How much sand, coarse aggregate and cement will be required to make the counterweight in problem 10? How many gallons of water?

12. How many cubic feet of 1:3 cement-sand mortar in 100 concrete sewer pipes with inside diameter 8 in., length 4 ft., thickness of wall 5 in.? What is the dry weight per pipe? Assume 1 cu.yd. of 1:3 mortar requires 9 sacks of cement and 27 cu.ft. of dry sand weighing 100 lb. per cubic foot.

13. Compute cement, damp sand and coarse aggregate required to build 1 mile of concrete road, width 20 ft., average thickness of slab 7 in.

Ping-pong tables of concrete are excellent for outdoor play.

Concrete shuffleboard courts are used by young and old alike.

14. What quantity of cement, sand, coarse aggregate and water will be required to construct 100 fence posts 5x4 in. at the base, tapering on two sides to 3x4 in. at the top, made 7 ft. long?

15. A concrete products plant has enough gang fence post molds to make 200 posts of size given in Problem 14. How many charges of a 2-sack batch mixer will be required to fill the molds?

16. Find cost of materials required to build a retaining wall 20 ft. long, 4 ft. high, 2 ft. thick at base and 1 ft. thick at top. Use quotations from your market.

17. Assuming that $\frac{1}{4}$-in. reinforcing bars weigh 0.167 lb. per foot, what will be the total weight of bars required to reinforce 100 posts as described in Problem 14, using 4 bars to the post?

18. Compute the amount of cement, damp sand and gravel required to construct a set of steps between a two-level sidewalk in which the horizontal distance between the two sections is 5 ft. Step risers are 7 in. high and treads are 12 in. wide. Steps are 4 ft. wide. Minimum thickness of concrete slab under steps is 5 in.

19. How many sacks of cement will be required to construct a concrete feeding floor 18 ft. square and 4 in. thick? How many gallons of water will be required?

A PRACTICAL COURSE IN CONCRETE

Solution to Problems on Pages 64-65

1. Reference: Table 1, page 18.

   Suggested mix for driveway is 1:2½:3½ using 1½-in. maximum size aggregate. Materials required to produce 1 cu.yd. of concrete are 6 sacks of cement, 15 cu.ft. of sand, 21 cu. ft. of coarse aggregate and $5\frac{1}{2}\times 6=33$ gal. of mixing water. Therefore, 8.5 cu.yd. of concrete will require 8.5 times these amounts, or *51 sacks of cement, 127.5 cu.ft. of sand, 178.5 cu. ft. of coarse aggregate* and *280.5 gal. of water.*

2. Reference: Table 1, page 18.

   Suggested mix for foundation walls is 1:3:4 using 1½-in. maximum size aggregate. Materials required for 1 cu.yd. of concrete are then 5 sacks of cement, 15 cu.ft. of sand and 20 cu.ft. of coarse aggregate. Since 1 cu.yd. of concrete is made with 5 sacks of cement, the number of cubic yards of concrete produced by 23 sacks of cement is found by dividing 23 by 5 $(23\div 5)=$ *4.60 cu.yd. of concrete.*

3. Volume of concrete in a wall is obtained by multiplying length by height by thickness. 10 in. $={}^{10}/_{12}$ ft.

   Length of wall $=2\times 62+2(31-1\frac{2}{3})=182\frac{2}{3}$ lin.ft.

   Volume of wall, therefore, is $182\frac{2}{3}\times 4\times {}^{10}/_{12}=608.9$ cu.ft.

   Deduct for openings ${}^{10}/_{12}\times 18=15$ cu.ft.

   $608.9-15=593.9$ cu. ft. $=$ *22 cu.yd.*

4. Reference: Table 1, page 18.

   Suggested mix for foundation wall is 1:3:4 using 1½-in. maximum size aggregate. Assume sand is damp. Then 6¼ gal. of mixing water is added for each sack of cement. Materials required for 1 cu. yd. of concrete are 5 sacks of cement, 15 cu.ft. of sand, 20 cu.ft. of coarse aggregate and $6\frac{1}{4}\times 5=31.25$ gal. of mixing water. Then 22 cu.yd. of concrete will require 22 times these quantities or *110 sacks of cement, 330 cu.ft. of sand, 440 cu.ft. of coarse aggregate* and *687.5 gal. of mixing water.*

5. Reference: Table 1, page 18.

   Suggested trial mix is 1:3:4, using 1½-in. maximum size aggregate. 1 cu.yd. of concrete requires 5 sacks of cement. 22 cu.yd. requires $22\times 5=110$ sacks of cement. $110\times 94=10{,}340=$ total weight of cement in pounds. If wagon or truck will carry 2 tons (4,000 lb.) then $10{,}340\div 4{,}000=$ *2.58 = number of loads (3 trips will be required).*

6. Reference: Table 1, page 18.

   Suggested mix is 1:2½:3½, using 1½-in. maximum size aggregate. Since 6 sacks of cement will produce 1 cu.yd. (27 cu.ft.) of concrete, then 1 sack will produce ⅙ of 27 or 4.5 cu.ft. of concrete.

   Sidewalk is 5 in. thick; therefore, each square foot requires ${}^{5}/_{12}$ cu.ft. of concrete. Then the number of square feet of sidewalk that can be made from 4.5 cu.ft. of concrete is found by dividing 4.5 by ${}^{5}/_{12}=10.8$, therefore, *10.8 sq.ft. of sidewalk* can be made with 1 sack of cement.

7. Reference: Table 1, page 18.

   Water required for each sack of cement is 5½ gal. Each cubic yard concrete requires 5 sacks of cement; therefore, mixing water required for 1 cu.yd. of concrete equals $5\times 5\frac{1}{2}=27.5$ gal. Then, 108 cu.yd. of concrete will require $108\times 27.5=2{,}970$ gal. Each tank wagon holds 20 bbl. $=$ 630 gal. Number of loads required to haul 2,970 gal. $=$ $2{,}970\div 630=4.71$ or *5 loads.*

8. Assume 1 bbl. holds 31.5 gal. of water (7.5 gal. equals 1 cu. ft.). Volume of tank (liquid capacity) is $\pi r^2 h$, where $r=$ inside radius and $h=$ depth of water. Therefore, volume of tank in cubic feet $=3.1416\times 9\times 9\times 15=3{,}817$ cu.ft. To convert cubic feet to gallons multiply $3{,}817\times 7.5=$ *28,627 gal.* To convert gallons to barrels, divide 28,627 by $31.5=$ *908.8 bbl.*

9. Reference: Table 1, page 18.

   Suggested mix for this work is 1:2½:3½, using 1½-in. maximum size aggregate. Materials required for 1 cu.yd. of concrete are 6 sacks of cement .15 cu.ft. of sand, 21 cu.ft. of coarse aggregate and $6\times 5\frac{1}{2}=33$ gal. of water.

   Volume of concrete in tank walls equals circumference at center of wall times thickness times height.

   Volume of 8-in. thick wall $=3.1416\times 18.67\times {}^{8}/_{12}\times 3=117.3$ cu.ft.

   Volume of 6-in. thick wall $=3.1416\times 18.5\times {}^{6}/_{12}\times 17=494.02$ cu.ft.

   Volume of concrete in tank floor is equal to area of floor multiplied by thickness, or $3.1416\times 9\times 9\times {}^{8}/_{12}=169.65$ cu.ft.

   Volume of concrete in footing is obtained by multiplying circumference at center of footing by width by depth $=$ $3.1416\times 18.67\times 1\times {}^{16}/_{12}=78.2$ cu.ft.

   Total volume of concrete for job $=117.3+494.02+169.65+78.2=859.17$ cu.ft.; 859.17 cu.ft. $=31.82$ cu.yd. (approximately 32 cu.yd.).

   To find total amounts of materials required for job multiply quantities required for 1 cu.yd. by 32:

   32×6 = *192 sacks of cement*
   32×15 = *480 cu.ft. of sand*
   32×21 = *672 cu.ft. of coarse aggregate*
   32×33 = *1,056 gal. of water*

10. Since counterweight of 15 tons (30,000 lb.) is required and each cubic foot of concrete weighs 145 lb., a total of 30,000 divided by 145 or 207 cu.ft. will be needed. Since space is 10×10 ft., there is 100 cu.ft. of concrete in each foot of height. Height required for 207 cu.ft. is therefore $207\div 100=$ *2.07 ft.*

11. Reference: Table 1, page 18.

    Suggested mix for this kind of work is 1:3:4, using 1½-in. maximum size aggregate. Materials required for 1 cu.yd. of concrete are 5 sacks of cement, 15 cu.ft. of sand, 20 cu. ft. of coarse aggregate and $5\times 6\frac{1}{4}=31.25$ gal. of water.

    207 cu.ft. of concrete $=7.67$ cu.yd.

Tberefore, materials required for 7.67 cu.yd. of concrete are:

7.67×5 = *38.35 sacks of cement*
7.67×15 = *115.05 cu.ft. of sand*
7.67×20 = *153.40 cu.ft. of coarse aggregate*
7.67×31.25 = *239.6 gal. of water*

12. Volume of mortar in pipe equals circumference at center times lengtb times thickness. Diameter at center of wall is 43 in.

Assume 1 cu.yd. of 1:3 mortar requires 9 sacks of cement and 27 cu.ft. of dry sand weigbing 100 lb. per cu.ft.

Volume of each pipe in cubic feet $= \frac{3.1416 \times 43 \times 48 \times 5}{1{,}728} =$ 18.76 cu.ft.

Volume of mortar in 100 sewer pipe $= 100 \times 18.76 = 1{,}876$cu.ft.

Weigbt of 1 cu.yd. mortar (dry) is weigbt of cement plus weigbt of sand.

9 sacks of cement weigb $9 \times 94 = 846$ lb.

27 cu.ft. of sand weigbs $27 \times 100 = 2{,}700$ lb.

Weigbt of 1 cu.yd. of mortar $= 2{,}700 + 846 = 3{,}546$ lb.

Eacb sewer pipe contains 18.76 cu.ft. of mortar = .695 cu.yd.

Weight of eacb pipe $= .695 \times 3{,}546 =$ *2,464.47 lb.*

13. Reference: Table 1, page 18.

Suggested mix for this work is 1:2½:3½, using 1½-in. maximum size coarse aggregate. Materials required for 1 cu. yd. of concrete are 6 sacks of cement, 15 cu.ft. of sand and 21 cu.ft. of coarse aggregate.

Volume of concrete in 1 mile of road $= 5{,}280 \times 20 \times {}^{7}/_{12} =$ 61,600 cu.ft. $= \frac{61{,}600}{27} = 2{,}281$ cu.yd.

Materials required for 1 mile of road are:

$2{,}281 \times 6$ = *13, 686 sacks of cement*
$2{,}281 \times 15$ = *34,215 cu.ft. of sand*
$2{,}281 \times 21$ = *47,901 cu.ft. of coarse aggregate*

14. Reference: Table 1, page 18.

Suggested mix for tbis work is 1:2¾:2¾, using ¾-in. maximum size aggregate. Materials required for 1 cu.yd. of concrete are 6½ sacks of cement, 18 cu.ft. of sand, 18 cu. ft. of coarse aggregate and 6½×5½=35¾ gal. of water.

Average cross-section of post is 4×4 in. = 16 sq.in.

Volume of post $= \frac{16 \times 84}{1{,}728} = .777$ cu.ft.

Volume of 100 posts $= 100 \times .777 = 77.7$ cu.ft. $= \frac{77.7}{27} = 2.88$ cu. yd.

Materials required for 100 posts:

2.88×6½ = *18.72 sacks of cement*
2.88×18 = *51.84 cu.ft. of sand*
2.88×18 = *51.84 cu.ft. of coarse aggregate*
2.88×35¾ = *102.96 gal. of water*

15. 2.88 cu.yd. concrete required to make 100 posts in Problem 14. Concrete for 200 posts $= 2 \times 2.88 = 5.76$ cu.yd.

Since 6½ one-sack batcbes are required for 1 cu.yd. of concrete, tben 3¼ two-sack batcbes are required for 1 cu.yd. of concrete. Total number of two-sack batcbes to make 200 posts $= 3.25 \times 5.76 =$ *18.72 (19) charges of a two-sack mixer.*

16. Reference: Table 1, page 18.

Suggested mix for this work is 1:3:4, using 1½-in. maximum size aggregate. Materials required for 1 cu.yd. of concrete are 5 sacks of cement, 15 cu.ft. of sand and 20 cu.ft. of coarse aggregate.

Assumed prices:
- Cement at \$1.00 per sack
- Sand at .07 per cu.ft.
- Coarse aggregate .10 per cu.ft.

Volume of concrete in retaining wall = 20×4×1½ = 120 cu. ft.; 120 cu.ft. = 4.44 cu.yd.

Materials required:

4.44×5	=22.20 sacks of cement at	\$1.00 =	\$22.20
4.44×15	=66.60 cu.ft. of sand at	.07 =	4.66
4.44×20	=88.80 cu.ft. coarse aggregate at	.10 =	8.88
	Total cost of materials		*\$35.74*

17. 100 posts with four reinforcing rods per post = 400 bars. Assume bars are eacb 6½ ft. long. Total lineal feet of bars required = 400×6½ = 2,600 lin.ft.

Weight of bars $= 2{,}600 \times 0.167 =$ *434.2 lb.*

18. Reference: Table 1, page 18.

Suggested mix for this work is 1:2½:3½, using 1½-in. maximum size aggregate. Materials required for 1 cu.yd. of concrete are 6 sacks of cement, 15 cu.ft. of sand and 20 cu.ft. of coarse aggregate.

Assume supporting slab 5 in. thick.

Volume of concrete in supporting slab equals lengtb times width times thickness. Length $= \sqrt{60^2 + 35^2} = 69.462$ in. = 5.79 ft.

$5.79 \times 4 \times 5/12 = 9.64$ cu.ft. in supporting slab.

Volume of concrete in eacb step equals area of triangles formed by tread and riser multiplied by widtb of steps.

Area of triangle $= \frac{12 \times 7}{2} = 42$ sq.in.

Tberefore, volume in eacb step $= 42 \times 48 = 2{,}016$ cu.in. $= \frac{2{,}016}{1{,}728} = 1.165$ cu.ft.

Volume of five steps $= 5 \times 1.165 = 5.83$ cu.ft.

Total volume of concrete $= 9.64 + 5.83 = 15.47$ cu.ft.

15.47 cu.ft. = .57 cu.yd.

Tberefore materials required for set of steps are:

$.57 \times 6$ = *3.42 sacks of cement*
$.57 \times 15$ = *8.55 cu.ft. of sand*
$.57 \times 20$ = *11.40 cu.ft. of coarse aggregate*

19. Reference: Table 1, page 18.

Suggested mix for this work is 1:2½:3½, using 1½-in. maximum size aggregate.

Volume of concrete in floor $= 18 \times 18 \times {}^{4}/_{12} = 108$ cu.ft. = 4 cu.yd.

1 cu.yd. concrete requires 6 sacks cement; therefore, 4 cu.yd. requires $4 \times 6 =$ *24 sacks of cement.*

Wben sand is damp, each sack of cement requires 5½ gal. of water; tberefore, 24 sacks require 24×5½ = *132 gal. of water.*